MINUTES AND PROCEEDINGS

of the

ARMY-NAVY-NRC VISION COMMITTEE

15th Meeting

12 - 13 February 1946

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MINUTES AND PROCEEDINGS

of the fifteenth meeting of the

ARMY - NAVY - NRC VISION COMMITTEE

12-13 February, 1946

National Academy of Sciences
2101 Constitution Avenue
Washington, D. C.

COPY NO. 98

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ARMY-NAVY-NRC VISION COMMITTEE
MINUTES

Fifteenth Meeting
National Academy of Sciences
2101 Constitution Avenue
Washington, D.C.

February 12-13, 1946

The following were present:

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Capt. Earl L. Green, School of Aviation Medicine, Randolph Field, Texas.

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(M)Col. W. H. Brucker

AGO
(M)Dr. Edwin R. Henry
Capt. Calvin W. Taylor, Personnel Research Section, AGO

Ord
(A)Mr. John E. Darr

QG
(A)Mr. M. N. Dokken

SG
Lt. Col. William C. Burry, Army Med. Research & Dev. Board
(A)Lt. Col. M. Elliott Randolph

NAVY

CNO
(A)Dr. George Kimball
Comdr. L. F. Volk, Ship Characteristic Board, CNO
Dr. Edward S. Lamar, Operations Evaluation Group, CNO

BuAer
(M)Lt. Comdr. Harry London
Lt. Clifford P. Seitz
Lt. (jg) Jesse Orlansky
Lt. Comdr. Harry H. Stuart
Ens. Brian O'Brien Jr., BuAer, Camouflage & Visibility Sect

BuMed
(M)Capt. J. H. Korb
(A)Lt. William K. Kuhlman
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Dr. D. F. Windenburg
Lt. Robert R. Hays, Visibility Theatre, D. T. Model Basin
Mr. Robert W. Sandburg, Visibility Theatre, D. T. Model Basin

BuPers	(A)Ens. James F. Curtis Lt. Comdr. Everett G. Brundage Lt. Comdr. A. Raskin, Div. of Curriculum & Standards Lt. John C. Snidecor, Curriculum Section
NAS	Lt. Henry A. Imus Lt. Richard Trumbull
NMRI	Lt. (jg) J. E. Birren
NRC	(M)Dr. George Byram (M)Dr. Conrad Berens (M)Dr. Detlev Bronk (M)Dr. Clarence H. Graham (M)Dr. H. K. Hartline (M)Dr. Selig Hecht (M)Dr. Walter Miles (M)Dr. Brian O'Brien (M)Dr. Richard Scobee (M)Dr. Derrick Vail (M)Dr. George Wald
NRL	Dr. Richard Tousey
ORI	(M)Comdr. Urner Liddel (M)Comdr. H. G. Dyke
SCBd.	Lt. Comdr. G. W. Dyson
SubBase	Capt. C. W. Shilling Lt. Comdr. Ellsworth B. Cook Lt. Comdr. John H. Sulzman Lt. Comdr. Dean Farnsworth Lt. (jg) W. S. Verplanck
Marine Corp	Major Roy L. Sherrill, Jr., Division P & P, Headquarters, USMC
	Dr. Howard S. Coleman, Penn. State Optical Inspection Lab. Dr. S. Q. Duntley Dr. Irvine C. Gardner Mr. Francis D. Harrington, Optical Design Laboratory, Naval Gun Factory Mr. D. M. Packer, Optical Design Lab., Naval Gun Factory Mr. Louis P. Harrison, U. S. Weather Bureau Dr. Hans H. Neuberger, Div. of Meteorology, Penn State College Mr. Samuel G. Hall Dr. Lindell C. Owensby, Barnes Hospital, St. Louis, Missouri Mr. B. DePoy, (SCB) Navy Department Dr. Donald G. Marquis Mr. H. Richard Blackwell

Tuesday, 12 February

1. The Chairman called for corrections or alterations in the Minutes and Proceedings of the 14th meeting. There were no corrections.

2. Dr. Marquis described the present administrative organization of the Committee. It was explained that a contract has been placed between the University of Michigan and the Navy Department, Office of Research and Inventions, for the Committee to continue its functions.

3. Lt. Comdr. Cook presented a paper entitled, "Comparative Study of Several Measures of Visual Acuity".- - - - - - - - - - - - - - - - - 9

4. Lt. Comdr. Sulzman presented a paper entitled, "Comparative Study of Measures of Phoria".- -59

5. Dr. Derrick Vail, Chairman, reported for the Subcommittee on Procedures and Standards for Visual Examination:

The manual, "Testing Heterophoria", prepared by the Subcommittee has been submitted to field testing centers for critical comment. Comment received from eye-testing centers in the Army and Navy revealed general enthusiasm for the manual. After discussion by the Committee, the following motion was passed:

VOTED: (1) That the manual of instructions, "Testing Heterophoria", prepared by the Subcommittee on Procedures and Standards for Visual Examination, be accepted with the following amendment:

That the adjustment of the prisms in phoria measurement be made by the examiner instead of the examinee.

(2) That the amended manual of instructions, "Testing Heterophoria" be forwarded to the appropriate offices of the Army and Navy with the recommendation that it be adopted for use by the armed services, inasmuch as it represents the consensus on heterophoria in the light of present knowledge. Should subsequent investigations uncover better methods of testing, suggested revisions of the manual will be forwarded.

The Manual is reproduced in the Proceedings - - - - - - - - - - 64
The Subcommittee met in Ann Arbor, Michigan, on December 11, 1945 to consult with personnel from the Office of the Adjutant General, U. S. Army, concerning an experimental program on visual acuity test charts. This program, to be described by Captain Taylor, A.G.O., was instigated largely through the efforts of members of the Subcommittee. Frequent consultations have subsequently been held between A.G.O. personnel and members of the Subcommittee.

6. Lt. Comdr. Farnsworth presented a brief statement of the purpose and results of the work of Dr. Franklyn D. Burger, who was unable to attend the meeting. A summary of the scheduled report, entitled "A Study of Acuity in the Mesopic Brightness Range in Relation to Refractive Error" is included in the Proceedings. - 76

7. Captain Taylor presented a paper entitled "The A.G.O. Research Program on Acuity Test Charts". - - - - - - - - - - - - - - - - - 79

8. Dr. Duntley presented a paper, prepared by Dr. A. C. Hardy, entitled "The Visibility Program of the NDRC Camouflage Section".- - 81

9. Dr. Duntley presented a paper entitled "Reduction of Target Contrast by the Atmosphere". - - - - - - - - - - - - - - - - - - - 81

10. Mr. Blackwell presented a paper entitled "Laboratory Studies of the Visibility of Targets". - - - - - - - - - - - - - - - - - - - 82

11. Dr. Duntley presented a paper entitled "The Calculation of Liminal Target Ranges". - 90

12. Dr. Duntley presented a paper, prepared by Dr. A. C. Hardy, entitled "The Effect of the Atmosphere on the Performance of Optical Instruments". - 90

13. Dr. Duntley was scheduled to present a paper entitled "Visibility of Targets on the Ground." Because time did not permit, the paper was not delivered. A summary of the paper is included in the Proceedings. - 91

Wednesday, 13 February

14. Lt. (jg) Verplanck presented a paper entitled "Results of Field Tests of Binoculars". - 95

15. Comdr. Brown presented a paper entitled "Visibility of Ships at Night". - 123

16. The Chairman called for discussion of long-range research plans in the field of vision. A digest of the discussion is included in the Proceedings. - 141

17. The Chairman called for discussion of desirable future activities of the Committee. After discussion, the following motion was passed:

VOTED: That a Subcommittee be appointed to establish means whereby equipment for visual research can be received, stored and made available on loan for use by various laboratories, civilian and military.

A digest of the discussion of future activities of the Committee is included in the Proceedings. - - - - - - - - - - - - - - - - - 157

18. ABSTRACTS OF CURRENT LITERATURE - - - - - - - - - - - - - - - - - 159

COMPARATIVE STUDY OF SEVERAL MEASURES OF VISUAL ACUITY

Lt. Comdr. Ellsworth B. Cook, USNR
Medical Research Department
U. S. Submarine Base
New London, Connecticut

COMPARATIVE STUDY OF SEVERAL MEASURES OF VISUAL ACUITY

Ellsworth B. Cook, Lt. Comdr., USNR

Introduction:

This paper is a brief resume of the work described in detail in Progress Report No. 2, entitled, "Visual Acuity Measurements With Three Commercial Screening Devices". These experiments were performed during November and December 1945, under BuMed Research Division Project No. X-495 (Av-263-P), entitled, "Comparison of Various Screening Devices with Standard Medical Procedure". Progress Report No. 2 is limited to a consideration of Visual Acuity; heterophoria is treated in Progress Report No. 3 and the results will be discussed later by Dr. Sulzman.

This project is an investigation of the validity and reliability of three instruments developed by different optical companies to measure daylight acuities and heterophorias:

A. Keystone Ophthalmic Telebinocular.
B. Bausch and Lomb Ortho-Rater.
C. American Optical Sight Screener.

From information at hand it appears that no adequate standards exist for the measurement of visual acuities. In the typical procedure of the U. S. Navy, the examiner called upon the subject to read letters on charts placed twenty feet away. If the subject's vision was so defective that he was unable to read any of the lettered lines established as appropriate for the twenty foot distance, he was instructed to step forward to the eighteen foot mark and to attempt again to read the test lines. This process was repeated, if necessary, by moving successively closer until a distance was reached at which he could read the lines satisfactorily. All too frequently the examiner had no criterion of what constituted a satisfactory reading. It is not surprising that the scores usually obtained from such a procedure have been shown to be unreliable; an acuity measurement by one examiner cannot be used to predict accurately the measurement by another. However, an examination of the problem indicated that much of the unreliability could be eliminated if certain simple and obvious factors were controlled. These factors include:

(1) Physical condition of the subject.
(2) Testing procedure.
(3) Test-target illumination.
(4) Test-target selection.

It was noted in Progress Report No. 1 that control of the first factor, for example, produced an immediate improvement in the reliability. Before any attempt was made to control the physical condition of the subject, many failed

their visual acuity tests. These failures did not reflect permanent visual deficiencies; instead they were transient effects resulting from long periods of travel, lack of sleep, or overindulgence in alcohol, the effects of which disappeared after adequate rest. The simple expedient of restricting the liberty of all subjects to the immediate vicinity for twenty-four hours prior to examination promptly reduced significantly theproportion failing visual tests. In this experiment brief health histories were taken in order to insure no one was subject to obvious transient disabilities.

The testing procedure was a second factor which desperately required standardization. Various examiners developed their own testing technique, thus throwing an obvious factor of inconsistency into visual measurements. Moreover, men with motives for passing or failing visual tests knew tricks which gained the desired objective. Such obvious cheating devices as chart memorization, peeking through fingers, squinting with the eyelids, deliberate misselling of letters, etc., have been observed. In order to render examinations at one activity comparable with examinations at others the Visual Standards Committee of the Army-Navy-OSRD Vision Committee recently compiled a "Manual for Testing Visual Acuity" in which the test procedure was standardized. All test operators in this experiment were supervised carefully to be certain that the prescribed procedures were followed.

The test-target illumination is another factor having a definite effect on the test score. It can be demonstrated readily that, within limits, as the illumination is increased, the better will be the test score for any man. Although this is an every-day fact known to everyone who hasn't been blind since birth, measurements at various military stations have revealed conditions of illumination on visual test charts varying from 3 to 300 foot candles. This serious inconsistency has been considered by the Visual Standards Sub-Committee of the Army-Navy-OSRD Vision Committee, and now specific brightness values are specified for the test chart and for the testing room. The specified illumination was used in this program.

At the present time no satisfactory standard test target exists. The Snellen Charts made by commercial firms are notoriously poor; for example, letter sizes for a given line differ by as much as 25% depending on the manufacturer. Furthermore, except by convention there is no particular reason that Snellen letters should be considered the most desirable test object. However, convention can be appealed to in the absence of any other basis for choosing standards. So conventional letter reading tests were selected arbitrarily as the standard against which the performance of these various screening devices were to be compared. The Snellen Charts were to be the standard target, but an analysis of preliminary data made it obvious that, because of wide variations in relative difficulties of letters, the Snellen Chart must be

modified. The data for difficulty of the letters on the modified chart (New London Chart) were more evenly distributed. The Chart is described in a later section. Statistical analysis of the data in this paper suggests there is room for improving the reliability further, but at any rate, the reliability of the New London Chart exceeds that obtained for the commercial Snellen Chart.

An adequate index of ability to see objects at any given distance should be a composite of several measures: measures of how well an individual resolves bright objects on dark backgrounds, objects with vague outlines, objects with strong light contrasts, objects with weak contrasts, objects made in various forms, colored objects, etc. Unfortunately, it is not feasible to develop such a composite index at this time. Instead it was agreed that for this study certain limitations to the index must be imposed; certain parameters that are crucial to the measures must be fixed arbitrarily. As a guide in selecting the variables to be fixed, it was determined that the indices should be in close conformity with what has been traditional in standard medical practice for measuring visual resolving power. Furthermore, the factors to be fixed should conform to specifications laid down by the Subcommittee on Standards of the Army-Navy-OSRD Vision Committee. Thus it was agreed that the objects would be exposed on a white screen with a brightness of 15 foot candles, the edges of the objects should be very sharply delineated, the distance from which far acuity should be measured would be 20 feet, and from which near acuity be measured would be 14 inches. The objects themselves should be black alphabetical characters constructed according to Snellen's specifications.

The index of resolving power for far objects is quite consistent. The correspondence between scores obtained on the first test and a second test is reflected in the product-moment correlation coefficient of 0.88. The index for resolving power for near objects is not as reliable; test-retest data show a product moment coefficient of 0.75. In order to enhance the reliability of the far and near indices further, the average of the test and retest scores was used. The calculated reliability of the average far score is approximately 0.94 and of the mean near score is 0.86.

The correlation between far and near indices was 0.65. In view of the reliabilities it is certain that different factors are involved in the two measures.

A visual measurement of increasing importance is near acuity. This index has been almost entirely disregarded by the Services to date, even though it is an established fact that a measure of an individual's far acuity is at best a poor indication of his ability to see satisfactorily at close hand. In other words, a man whose vision permits him to serve successfully as a horizon lookout may be inefficient

at reading dials, oscilloscopes, etc., a few feet away. Consequently, it is of extreme importance that men chosen for various near-vision operations be carefully selected on the basis of their near-vision measurements, and not be assigned such duties on the basis of far-vision examinations as is the current practice.

The heterogeneity in visual ability of the population on which the findings in this study were developed is probably comparable to that of a population that might be examined by a national military selective service. The population was comprised of Navy Personnel (enlisted men, Waves, and chief petty officers), male and female civil service workers, male high school seniors. Of course, had the population been more heterogeneous the validity and reliability coefficients throughout the study would be increased correspondingly. The significant point is that the study was conducted on a group that is fairly representative of the population in which military medicine is interested. The devices under study are evaluated for use in military practice. To the extent that the persons on whom the statistics are based is a representative sample of the group on which the devices might be used, the statistical reports of validities and reliabilities are valid for the purposes of the investigation. On the other hand, the problem of comparative function of the three instruments is not so dependent upon the natureof the population; comparative data might indicate which were the most satisfactory devices even if the groups were not at all representative. However, since one of the objectives of this investigation must be to establish some notion of score distributions and standards, the problem of range of ability is vital.

Because of the heavy loading of the sample with young men chosen for a particular branch of the military service, the sample is probably more homogeneous than ophthalmologists may expect to encounter in civilian practice. Thus it is probable that the reliability and validity data can be increased for application to civilian ophthalmological practice. In other words, the findings reported herein may be considered very conservative for ordinary civilian ophthalmological purposes.

A total of 128 observers were measured in a test-retest situation. The total was comprised of the following groups:

Group	Number
(1) USN Enlisted Men	47
(2) USN Chief Petty Officers	21
(3) USN Enlisted Waves	20
(4) Civil Service Workers Male and Female	20
(5) High School Students - 12th grade - Male	20

The distributions of far acuity scores for the component groups of this population are presented in Table I.

Procedure:

The visual tests were conducted in various screened compartments of a large well-lighted and well-ventilated room. Reading material was provided for the subjects awaiting tests and an atmosphere of quietness prevailed. Subjects were permitted to smoke, read and converse in low tones between tests. No one was informed of his score, and all were assured that the results would have no bearing on subsequent service or duty status. Intervals between tests were spaced in an effort to reduce to a minimum any effects due to fatigue factors. Very few subjects complained of any ocular discomfort during or following the day of examination.

The observers were tested in groups of eight and the experimental procedure permitted two such groups to be tested each morning and retested the afternoon of the same day. The order of tests was completely randomized from person to person by the Latin Square technique. The retest order for each subject duplicated the test procedure.

For the first fifteen minutes the subjects composing a test group gathered in the testing room. Each testee was given a brief questionnaire concerning his general health for that day. Aside from the routine information of name, rate, age, etc., they were asked to record any recent illnesses or visual difficulties felt at that time. Since it was impossible to control the activities of the subjects on the day prior to testing, statements as to the amount of sleep, and alcohol ingestion were obtained. On the basis of these records it was possible to eliminate any subject from the test situation if such admitted conditions as hangovers, eye infections, stomach upset, etc., warranted it. With the questionnaire as a guide it was not found necessary to eliminate any subject. After the questionnaire had been completed, a small typewritten card was given to each person. This card showed his name, serial designation, and the test sequence which he was to follow. Each of the eight tests was assigned a letter designation from A. through H. as follows:

A - - - - - - - - - - - - - - - - 20' test
B - - - - - - - - - - - - - - - - Maddox Rod
C - - - - - - - - - - - - - - - - Ortho-Rater No. 1
D - - - - - - - - - - - - - - - - Ortho-Rater No. 2
E - - - - - - - - - - - - - - - - Telebinocular
F - - - - - - - - - - - - - - - - Sight Screener
G - - - - - - - - - - - - - - - - I.P.D.
H - - - - - - - - - - - - - - - - Near Acuity-New London Test

Table I

Group vs. New London Far Average Acuity Test

Each eye is considered a single datum. The numbers on the ordinate are in decimal equivalents of Snellen fractions times a factor of 10.

New London Far Average Acuity Test	Civil Service Male & Female	U.S.N. Enlisted WAVES	Male High School Seniors	U.S.N. Chief Petty Officers	U.S.N. Enlisted Men	Total
0	3	1				4
1	2	1				3
2	2	1	9	5		17
3						
4	4	1	2	2	1	10
5						
6	5	1	1	7	2	16
7						
8	7	10	5	11	16	49
9						
10	10	11	5	7	27	60
11						
12	3	10	10	9	27	59
13						
14	3	3	6	1	12	25
15						
16	1	1	2		6	10
17						
18					2	2
19						
20					1	1
Total	40	40	40	42	94	256

Each test compartment was clearly marked with its letter designation to facilitate the routing of each subject. Since the test procedure was designed to handle eight subjects at a time the randomization series was set up in 8 x 8 blocks rotating subjects against test. Thus it was necessary to prepare sixteen such blocks to provide for the 128 subjects used. Each of the blocks was assigned a letter designation from A. through P. and each subject was in turn given a numerical assignment from one through eight. Hence a man designated as 4-D could be located as the fourth subject in block D, and the block letter in turn would show the test sequence he followed.

Prior to the test a short talk was given to each group explaining briefly the purpose of the experiment, the test procedure and the importance of adhering rigidly to the test sequence assigned to each individual. As an added precaution each examiner checked off the subject's sequence card the letter representing his test upon its completion. In this way it was possible to maintain the proper testing sequence. When a subject had completed all of his tests this card was collected and checked against the data sheets as an additional safeguard. The same test sequence was followed for each man in the retest.

In order to present the Snellen and New London letters always at the same position a special drum was constructed. It consisted of a wooden cylinder three feet in diameter and 28 inches long. Wooden slats were nailed around the outer circumference of the drum and so spaced that it would be possible to present each test line singly. One of the various lines for each of the two test charts used (Snellen and New London) were tacked side by side to a single strip. By rotation of the drum any individual line could be viewed through a rectangular aperture cut in a large plywood panel located directly in front of the drum. Two such adjacent apertures permitted either one or both of the lines on a given strip to be presented. The centers of the apertures were 52 inches from the deck. The left hand aperture was five inches wide by twenty inches long and the corresponding right hand opening five inches wide by twelve inches long. Wooden shutters for either aperture could be dropped into place in order to expose the test charts singly if so desired. Snellen lines were always presented through the right hand opening, and the New London lines through the left. Both the drum and the slots were remotely controlled by the examiner from a position beside the observer.

The drum mechanism was mounted at one end of a visual range built in accordance with the specifications outlined by the Visual Standards SubCommittee of the Army-Navy-OSRD Vision Committee for visual testing rooms. A grey fabric with a reflection value of approximately 50% was hung from the ceiling to enclose the range. Lights were installed overhead, and shielded from the observer to supply the even illumination

specified. The brightness of the test target was approximately 15 foot candles, and the walls of the range were approximately 11 foot candles.

The commercial Snellen Charts were presented to the subjects as described before. The subject was seated at a distance of 20 feet from the test objective, with the examiner seated to one side and slightly behind. An occluder was used for testing each eye separately. The test order in all cases for this test was right eye, left eye, and both eyes. A standard method of test administration was developed which provided for starting with the second largest letters (the 0.2 line) and reading each successively smaller line until two errors were made in a single line. The score would then be the line immediately preceding the one in which the two errors were made. For example, if a subject read through the 1.0 line without an error, made one error in the 1.3 line, followed by two errors in the 2.0 line, his score would be 1.3. In the event that an observer was unable to read any of the letters in the first line presented, the largest letter was shown. If he was unable to name this letter, a score of zero was assigned. All measurements for the Snellen Charts were made at a distance of 20 feet.

The same method was used for presenting the New London Charts.

One of the Telebinocular near acuity tests consisted of a series of twenty-two small circles arranged about the circumference of a large circle. These small circles were of three types. The three types were lines, dots and uniform grey. Each of these circles was consecutively numbered from 1-22 and they became increasingly more difficult as the numbers increased. The observers task in this test was to indicate which of the three choices (lines, dots, grey) best described each small circle. There were three cards provided for the test, each with twenty-two circles. One card was used in testing the left eye, another both eyes, and the third, right eye. Thirteen key circles of the twenty-two were the basis for scoring. As this test had never been used previous to this experiment, no standard scoring method had been devised. The Keystone Company suggested that a subject be allowed to report on each of the twenty-two circles and the score be computed for an individual according to his success from 0 to 13. However, in order to expedite the test, and to make the psychophysical method reasonably comparable to that used with the other two screening instruments, the suggested procedure was defined further. The score was defined as the last circle identified correctly before two consecutive errors. This method was used with all subjects. For all the near tests the slide holder on the instrument was maintained at the sixteen inch point.

Results:

The results are best presented in tabulated form as shown in Tables II-VII. They are grouped in this section for convenience in referring to them.

In the main report the results are discussed in detail but in the present paper this section is limited to a tabular presentation of the data.

TABLE II

Test-Retest means, standard deviations and reliability coefficients for monocular acuity tests.

TEST	Test MEAN	Test S.D.	Retest MEAN	Retest S.D.	R
New London-Far	9.95	3.868	10.00	3.945	0.877
New London-Near	7.47	2.551	7.77	2.613	0.754
Sight Screener-Far	10.42	3.400	10.66	3.390	0.844
Sight Screener-Near	10.28	3.019	10.55	3.266	0.765
Telebinocular-Far	10.41	3.674	10.47	3.845	0.813
Telebinocular-Near (Circles)	8.69	2.109	9.16	2.115	0.708
Ortho-Rater No. 1-Far	10.54	2.795	10.81	2.459	0.850
Ortho-Rater No. 1-Near	10.34	2.303	10.66	2.214	0.848
Ortho-Rater No. 2-Far	10.52	2.536	10.78	2.540	0.817
Snellen-Far	11.79	4.375	12.01	4.441	0.797

The mean values are acuity scores in decimal equivalents times a factor of 10. N = 256; each eye considered a single datum.

TABLE III

Test-Retest means, standard deviations and reliability coefficients for binocular acuity tests.

TEST	TEST MEAN	TEST S.D.	RETEST MEAN	RETEST S.D.	R
New London-Far	11.85	3.520	12.34	4.107	0.824
New London-Near	9.74	2.645	9.79	2.872	0.666
Sight Screener-Far	11.59	3.373	11.62	3.223	0.698
Sight Screener-Near	11.68	2.987	11.70	3.092	0.703
Telebinocular-Near (Snellen)	15.03	5.119	15.45	5.127	0.650
Telebinocular-Near (Circles)	9.35	1.839	9.76	1.780	0.720
Snellen-Far	12.99	3.954	13.25	4.165	0.806
Ortho-Rater No. 1 Far	10.76	2.232	10.97	2.271	0.879
Ortho-Rater No. 1 Near	10.34	2.059	10.76	1.967	0.856

The mean values are acuity scores in decimal equivalents times a factor of 10. N = 128.

TABLE IV

Validity coefficient (R_v), and standard error of estimate of New London far average score for Monocular far acuity tests. N = 256.

TEST	R_v	Standard error of Estimate	Percentage Prediction Efficiency
Sight Screener-Far	0.743	2.548	33.1
Telebinocular-Far	0.585	3.088	18.9
Ortho-Rater No. 1-Far	0.721	2.638	30.7
Ortho-Rater No. 2-Far	0.721	2.638	30.7
Snellen-Far	0.825	2.152	43.5

The Standard Deviation for the New London Far Average Test is 3.807.

TABLE V.

Validity coefficient (R_v), and standard error of estimate of New London Far Average Score for binocular far acuity tests. N = 128.

TEST	R_v	Standard Error of Estimate	Percentage Prediction Efficiency
Sight Screener-Far	0.709	2.654	29.5
Ortho-Rater No. 1 - Far	0.794	2.288	39.2
Snellen-Far	0.772	2.392	36.4

The Standard Deviation for the New London Far Average Test is 3.764.

TABLE VI

Validity coefficient (R_v), and standard error of estimate for New London Near Average Score for monocular near acuity

N = 256.

TEST	R_v	Standard Error of Estimate	Percentage Prediction Efficiency
Sight Screener-Near	0.713	1.677	29.9
Telebinocular-Near (Circles)	0.552	1.994	16.6
Ortho-Rater No. 1-Near	0.746	1.592	33.4

The Standard Deviation for the New London Near Average Test is 2.391.

TABLE VII.

Validity coefficient (R_v), and standard error of estimate for New London Near Average Score for binocular <u>near</u> acuity.

N = 128

TEST	R_v	Standard Error of Estimate	Percentage Prediction Efficiency
Sight Screener-Near	0.639	1.935	23.1
Telebinocular-Near	0.553	2.097	16.7
Telebinocular-Near (Circles)	0.586	2.038	19.0
Ortho-Rater No. 1-Near	0.700	1.797	28.6

The Standard Deviation for the New London Near Average Test is 2.516.

Discussion:

Snellen Test.

The mean test-retest score for the right and left eye acuities lies intermediate between the 1.0 and 1.3 lines on the Snellen Chart, the very point where there is a gap in score range was the most common acuity level for this group. To some extent the inherent insensitivity of the test may be responsible for this result. The distribution of scores for other tests in this experiment indicate such to be the case. In other words, if an intermediate step were to be included between 1.0 and 1.3, a more exact measure might be obtained on a large part of the population. However, the problem of accurate visual acuity measurements cannot be adequately answered until many more facts have been assembled.

New London Test.

The relatively normal spread of scores over the score range of the New London Test is contrasted with that for the commercial Snellen Chart. The latter type of distribution probably is an artefact of the difficulty levels; and, in addition, it seems that it is a fairly reliable test as determined from its (r) values of 0.88 and 0.82 for single and binocular acuities respectively. The mean single eye scores for test-retest of 1.00 are slightly lower than the scores reported for the Snellen Chart. However, the difference could be due to a number of factors. The lines of the New London Chart are composed of equated characters, and the average difficulty in the several lines may vary from the corresponding lines on the commercial charts. Moreover, two extra lines have been incorporated in the range between 1.0 and 1.5, so that many persons who would otherwise be scored 1.0 may make higher scores even if unable to make 1.5. There is reason to believe that morework on relative difficulties of test characters, combined with minor changes in letter design, would render the New London Test still more reliable. As it now stands, it yields more consistent results than any of the other acuity tests in this study; but there is still room for major improvement.

The test-retest reliability coefficient for monocular and binocular near acuities are much lower than those obtained for the corresponding far acuities. One possible explanation for this decreased reliability is that the photographic reductions prepared for this test were not exact. This was especially true for the reproductions of the smallest test letters, where the edges of the individual letters were not distinct. A second possibility is that fixation and accommodation may be fluctuating more for the near distance, and thus may be throwing additional variance into the data. In any event the consistency of measurement is not considered satisfactory, and it is felt that more fundamental research on this problem is indicated.

The mean test-retest scores for both monocular and binocular acuity are lower than the corresponding far acuity scores. Several hypotheses might be advanced to account for this phenomenon of apparent increase in difficulty. The agreement between mean test and retest scores is excellent, so the learning factor during the first test is negligible.

However, despite its deficiencies, the New London Near Acuity Test was accepted as the best available, and it was assumed as the standard near test. All other near acuity measurements were compared with it as the validity standard.

Ortho-Rater.

The reliability values shown in the tables above are in full accord with those reported in Progress Report No. 1. This instrument possesses an acuity test with a reliability which, in the light of reliabilities of other acuity measures, is considered reasonably adequate.

Two Ortho-Raters with test slides carefully matched for density value were used. This was done in order to compare the performance of two separate instruments in a situation where observer differences and test-retest differences might be considered eliminated, and, evidently, when those differences can be eliminated, there are no instrument differences. At least almost identical reliabilities, validities, means and variabilities were obtained for the two, so it is reasonable to assume that apparent instrument differences for a given population must be based on differences in test targets.

The reliability coefficients for both monocular and binocular data are in close agreement with the corresponding values obtained for the far acuities. The mean test-retest scores are practically identical for both monocular and binocular acuities. The mean test scores are also very close to the corresponding means for the far tests.

Sight Screener.

The reliability of readings for individual eye for the Sight Screener is reasonably high and is practically identical to the reliability computed for the Ortho-Rater. However, the binocular acuity reliability coefficient is slightly lower than the values obtained for the Ortho-Rater. No explanation is offered for this discrepancy. The validity coefficient is also of the same order as the Ortho-Rater for single eye readings, and the mean scores for the Sight Screener for monocular acuity are practically identical to the scores obtained with the Ortho-Rater. Thus it would seem that for single eye screening, both instruments are measuring the same function, with a similar consistency, and with about the same score scale. The validity coefficient of this test in terms of New London Far criterion for monocular acuity is actually slightly

greater than that obtained for the Ortho-Rater while the converse reduction is probably attributable to the lower reliability of the Sight Screener binocular measure.

The slight differences are not large enough, however, to assign greater validity to either instrument. Just as with the Ortho-Rater, the score on the criterion New London Test can be predicted with approximately 30% greater accuracy from a Sight Screener reading than by chance. No differences between these instruments in respect to ease of administration, scoring, etc., are reported by operators who have used both, and both instruments possess minor mechanical difficulties which slight modifications in design would eliminate readily.

The reliability coefficients for the monocular near acuity data is somewhat lower than the corresponding figures for far acuity. Incidentally, the difference closely approximates that found for the Ortho-Rater. However, there was no significant difference in reliabilities for the binocular near and far data.

The validity data for the monocular measurements are slightly lower than those obtained for the far test. A similar decrease is noted also in the binocular data. However, the values obtained indicate that a reasonable validity exists, and, as pointed out with the other tests, the lower reliability in the near criterion itself must lead one to expect lower validity coefficients. Coefficients in this paper are not corrected for imperfect reliability.

Telebinocular.

The test-retest reliability of the Telebinocular for monocular distance acuity was found to be of the same order as for the other two screening devices, the actual coefficient being only slightly less than that obtained for the Ortho-Rater and the Sight Screener.

The reliability coefficients obtained for the near "circle" test were somewhat lower than the monocular scores yielded by either of the other instruments. However, this particular test is a new development and with more work may show satisfactory reliability. The test-retest consistency of binocular near data for the "circles" test is probably greater than that for the Snellen type test in this instrument.

A partial explanation for the lower reliability lies in certain mechanical and optical imperfections in the current model. It is understood that an improved instrument will be released in the future by the Keystone View Company.

Summary:

Results are presented on comparative efficiencies of three instruments (Keystone Telebinocular, Bausch and Lomb Ortho-Rater and American Optical Sight-Screener) for measuring visual acuity.

In order to compare the instruments with a reasonable standard, it was necessary to construct indices for near and far acuities that are more reliable than scores with commercial Snellen Charts. These improved measures were employed as criteria for assessing the validity of the scores yielded by the three instruments.

The comparative reliability of each of the devices was determined by computing the consistency of measurement. 128 observers were examined twice and the reliability was calculated by analyzing the data on first and second examinations.

Of the three instruments, the Keystone Telebinocular proved inferior in both validity and reliability to the Ortho-Rater and the Sight Screener. No choice between the other two is indicated, in the opinion of the speaker.

In every instance, the reliability of measures of acuity for distance is greater than the reliability of measures for near.

Evidence is presented showing that selection of personnel for near-point operations should be based on near acuity measures rather than on far acuity measures.

The reliability of measurement with screening instruments, (following procedures prescribed by the manufacturers), is inferior to that of letter-chart tests conducted according to the method outlined herein. However, the reliability of any test may be modified by simple changes in test procedure.

Discussion:

Dr. Hecht asked if it could be concluded that elaborate devices constructed for testing visual acuity were actually not more satisfactory than a simple letter chart fastened to the wall.

Lt. Comdr. Farnsworth replied that such a conclusion was not justified. He asserted that the letter chart used was "in effect a 20-foot instrument," provided with standard illumination and with a drum which facilitated the presence of a single letter at a time. He predicted that any of the instruments under discussion would be more reliable than the usual method of visual acuity testing.

Dr. Scobee questioned the use of the New London letter chart as a "yardstick" for the instrument tests.

Lt. Comdr. Farnsworth described in some detail the precautions which had been taken with the New London letter chart and reported that the reliability of the test was 0.94. He expressed the opinion that the New London chart was as reliable as any test of visual acuity could be and that the unreliability remaining in performance is due to basic physiological variation in the visual acuity function.

Dr. Henry cautioned that the high retest correlations for the various tests of visual acuity should not be construed as reliability measures to be expected in retests in the field.

Lt. Ross questioned Lt. Comdr. Cook's conclusion that the Keystone Telebinocular Test was less desirable than the other instruments since a casual examination of the data seemed to indicate comparable results for all the instrument tests.

Lt. Comdr. Cook pointed out that certain undesirable factors in the Keystone Telebinocular performance did not appear in the correlation data. He emphasized that bad lumpings of test scores exist at several points in the test scale.

Lt. Comdr. Farnsworth added the opinion that the Keystone instrument was in extremely poor adjustment and that numerous changes had to be made before reliable measurements could be made. In comparing the Keystone Telebinocular with the Ortho-Rater or the Sight Screener, he emphasized that the latter two instruments could not be used improperly, whereas the Telebinoculat demanded great care in administration of the test.

Dr. Henry pointed out that the results reported were representative not of performance of the Keystone Telebinocular, but rather of performance of a new improved test.

Dr. Berens discussed the differences in illumination in the test fields of the various instruments. Differences exist for the same instrument with different test objects. This variability was considered a source of undesirable variability in visual acuity measurements.

Dr. Graham asked whether an estimate could be made of the reliability of the various visual acuity tests for the general population.

Lt. Comdr. Cook stated that whereas no experimental evidence was available, it seemed likely that higher reliability would be obtained with the general population than with the selected group used in the New London tests. Lt. Comdr. Cook reported that 50% of his group of high school students had visual acuity of 20/20.

Lt. Imus reported that various tests in the Army indicated 20/20 vision in from 60% to 80% of the normal population, depending on the age group selected.

Lt. Comdr. Farnsworth suggested that the acuity tests could be used on large numbers of Army inductees if it were felt desirable that reliability measures be obtained for an unselected population.

Ensign Curtis remarked that the use of standard scores in the analysis of the New London data was not wholly justified in that the scatter diagrams did not indicate equivalent scatter for all scores. A further investigation of the nature of scatter diagrams in tests of visual acuity might be important if visual tests were shown to be valid indices of success in the armed forces.

COMPARATIVE STUDY OF MEASURES OF HETEROPHORIA

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COMPARATIVE STUDY OF MEASURES OF HETEROPHORIA

John H. Sulzman, Lt. Comdr., (MC) USNR

General Introduction

1.

Lt. Comdr. Cook has described the general procedures for the battery of tests used in the present experiment. The procedure which was employed in the clinical measure of phoria described in the second portion of this report is that recommended in the "Manual of Instructions for Testing Heterophoria" (1). This manual, developed by the Subcommittee on Procedures and Standards for Visual Examinations, is included in the Minutes of this Meeting.

Some of the references published between 1939 and 1944 will be found in the "Bibliography of Visual Literature" (2) compiled with the assistance of members of the Vision Committee. Additional information regarding the terms used herein and a brief description of tests for heterophoria will be found in the Minutes of the Twelfth Meeting (3) 12 June 1945. Another discussion of the subject will be found in the Minutes of the Fourteenth Meeting (4) 11-12 September 1945. The latter paper contains much of the experimental work upon which the present study is based.

2.

There has been a great deal written on the function of the extraocular muscles. Anyone who makes an effort to review the literature is overwhelmed by the number of published articles and by the great variety of tests advocated. Indeed, there are so many methods for measuring heterophoria that the impartial investigator might conclude that no one test has outstanding merit. To put it another way, one can find published authority for almost any viewpoint on this important subject. As Cridland (5) has expressed the matter:

> "The diversity of the available methods is only equalled by the diversion which some of them engender. The fantastic elaborations of the instrument maker have introduced further complexity, so that the patient, when faced by an imposing mass of machinery, may be easily forgiven for his failure to relax, and the element of voluntary effort becomes a thundercloud obscuring the entire heterophoria horizon. The wonder is that the results of measurement by different tests are not even more contradictory than they are."

The present paper is justified only if some necessary clarification of the current confusion is achieved. In the interests of brevity, references to specific authorities

will be held to a minimum. The investigator who desires to pursue any particular phase will find an abbreviated bibliography appended.

3.

As has been indicated, the number of available tests is extensive. A paper by Wheeler (6) reviews the measures which were first developed. Some of the early investigators devised methods which are worth study, and the principles laid down at the beginning have changed very little. It may be stated here that, at the present time, a majority of ophthalmologists employ either the cover test and its modifications, the Maddox rod test in some form, or a combination of these.

The problem under consideration differs from that of the practicing civilian eye specialist. These clinicians have the advantage of much experience with all degrees of ocular motility including the obviously abnormal. However, the problem which confronts the military services is rarely one of differential diagnosis of ocular muscle conditions. The main objective is the screening of large numbers of men in order to reject those who are unfit. Additional requirements for a measure which is desirable from the military standpoint will be discussed later.

In the present experiment no attempt has been made to evaluate all of the available measures of heterophoria. Such an encyclopedic study would present a monumental task and certainly would not be worth the effort. The limitation can be indicated in titles for the two parts into which this paper is divided. These are as follows:

Part 1. Comparison of three clinical methods for lateral heterophoria: Maddox rod, screen-Maddox rod, and screen and parallax.

Part 2. Comparison of the Maddox rod test for lateral and vertical heterophoria, with phoria tests incorporated in three visual screening devices; Keystone "Telebinocular", Bausch & Lomb "Ortho-Rater" and the American Optical "Sight Screener".

Part 1. COMPARISON OF THREE CLINICAL TESTS FOR LATERAL HETEROPHORIA

Introduction

Mention has already been made of the general categories into which the most accepted measures of heterophoria can be grouped. Two of the techniques evaluated in this report are in common use by ophthalmologists generally (5) (7) (8) (9)

but with some qualifications by individual writers (10) (11) (12) (13) (14). These are: (1) the Maddox rod and (2) the screen and parallax or cover test. A third method, (3) the screen-Maddox rod, is prescribed for the aviation medical examination for the Army and Navy (15) (16).

It might be stated parenthetically that tests which employ any type of stereoscopic instrument have been criticised by various authorities (13). One of the most common objections has been stated by Verhoeff (14) as follows:

> "Tests for presumptive heterophoria made by use of a stereoscope of any kind are especially unreliable because the observer has no accurate idea of the distances concerned."

In order to appreciate fully the extremes of viewpoint, one writer (17) assumed that occlusion of one eye for a week is necessary to elicit all the presumptive heterophoria! Fortunately, this opinion has not been entertained seriously by military surgeons.

Out of such a variety of usage and opinion, the experimental work of Gridland (5) and of Scobee (4) are outstanding as probably the first attempts to evaluate several methods of measuring heterophoria by assessing them on the basis of statistical evidence and analysis. Although Scobee has not presented his findings before the Committee, the results have been described to the Subcommittee on Procedures and Standards, and are published in the Minutes of the Fourteenth Meeting.

From the evidence of experimental studies, Captain Scobee at that time recommended:

1. That since the correlation of the Maddox rod test with the screen and parallax test is as high as the correlation of the screen and parallax test with the screen-Maddox rod test, the Maddox rod test may be used for measuring heterophoria.

2. That the Maddox rod test is easier to standardize and should be substituted for the more complicated screen-Maddox rod method.

3. That the factors of placing the Maddox rod before the dominant eye and the brightness of the room do not affect the measures elicited.

4. That the Maddox rod should be white instead of red.

5. That phorias should be measured at distances of 20 feet and 13 inches.

In the light of Scobee's studies, it was decided that before visual screening devices could be evaluated for their competence to measure heterophoria, three of the most acceptable clinical methods for this purpose should be compared. The most promising clinical test then might be applied as a validation criterion for the comparison of instruments.

Procedure

One hundred subjects were chosen at random from among the candidates for the Submarine School. Groups of ten men were tested twice during the same half-day, each time at distances of 20 feet and 13 inches, using the following order in each case:

1. Maddox rod (white)
2. Screen-Maddox rod (white)
3. Screen and parallax

All measurements were made by one examiner in a lighted room. In each case, a one cm. light was viewed at a distance of twenty feet without glasses and the examiner adjusted the Risley prisms of the phorometer. Since the vertical deviations were not being measured, the Stevens phorometer attachment was not used. A procedure wherein the examiner adjusted the prisms was selected in order to compare such measures with those to be performed later wherein the subject adjusted the prisms. Prior to the test the phorometer frames were centered and leveled accurately and the white Maddox rod was rotated into position before the right eye.

The first measure was made with the Risley prism in place behind the Maddox rod, the prism being set so that the subject perceived a vertical white streak of light to the left of a white light. It was demonstrated to the subject that the streak could be moved laterally, and he was directed to inform the examiner when the streak lay directly through the light. Next, the test was repeated while the right eye was covered intermittently, thus adding the screening factor to the Maddox rod test. The reading for the second test was likewise the prism position at which the subject reported that the line covered the light. The third test was performed after the Maddox rod had been rotated out of the line of view so that the subject viewed the light with each eye; a cover was placed before each eye alternately, while the prism was adjusted until the subject reported no apparent lateral movement of the light. The prism position was then taken as the third reading.

At the completion of the above tests at the twenty foot distance, the light was occluded and the subject's gaze was directed at the bulb of a lighted ophthalmoscope at a distance of thirteen inches from his eyes, exactly in the mid line and

at eye level. The ophthalmoscope handle was secured by means of tape to the bar attached to the phorometer, and swung into position after the distance testing had been completed. The same three tests were then performed at the near point, in the corresponding order and in exactly the same manner.

At the completion of the test-retest series, the data were plotted on scattergrams and subjected to statistical analysis.

Results and Discussion

No discussion of measures for heterophoria is complete unless the inherent variability of this function is emphasized. One authority (18) states the situation as follows:

> "If heterophoria tests are repeated several times under apparently equal conditions, the results obtained in those tests will very frequently differ, and this not only with respect to the amount but occasionally also with respect to the kind of existing heterophoria."

Since retesting heterophoria yields results of uncertain variation, a coefficient of test-retest correlation is not the only criterion of consistency which should be applied. The differences between test and retest means must be evaluated, and the reliability coefficient must be considered in the light of relative variabilities.

From the data presented in Table I, the Maddox rod test for phoria compares favorably with the other two methods at both distances. One sees from the relative standard errors of estimate that the results of a second distance examination with the Maddox rod can be predicted after a first examination, with more precision than a second screen-Maddox rod from a first screen-Maddox rod test. Note that it is assumed that one test of muscle balance does not affect the score for a later test; the order of testing was not altered from one individual to the next. There is some indication from the means in Table I that this assumption is not valid for the near tests.

In Table II one notes that the intercorrelations are as high as the inherent reliability in each measure allows; in other words, insofar as one can judge from these data, all three tests may be measuring identical functions.

Another aspect of fundamental importance must be stressed; that is, the question of what a method measures. There is a distinction between methods which employ simultaneous binocular fixation, such as the Maddox rod, and those in which the amount of ocular deviation is measured when binocular fixation is interrupted, as in covering each eye alternately. The screen-Maddox rod and the screen and parallax tests are examples of the latter type. In other words, the validity of measurement is critical. Unfortunately, there is as yet no standard which can be recognized generally as valid.

TABLE I

Test - Retest Consistency

A. Lateral heterophoria at twenty feet

Method	Correlation Coefficient	Test Mean	Test S.D.	Retest Mean	Retest S.D.	Standard error of retest estimate
Maddox rod	0.87	E .88	2.295	E .88	2.368	1.18
Screen-Maddox rod	0.89	E 1.37	2.784	E 1.30	3.106	1.43
Screen and parallax	0.72	E 1.42	2.741	E 0.47	2.579	1.79

B. Lateral heterophoria at thirteen inches

Method	Correlation Coefficient	Test Mean	Test S.D.	Retest Mean	Retest S.D.	Standard error of retest estimate
Maddox rod	0.74	X 3.87	4.50	X 4.99	4.896	3.53
Screen-Maddox rod	0.82	X 4.24	4.984	X 5.40	5.654	2.25
Screen and parallax	0.67	X 6.06	6.782	X 7.71	5.638	4.14

TABLE II

Test Intercorrelations

A. Lateral heterophoria at twenty feet

	Maddox rod	Screen-Maddox rod	Screen and parallax
Maddox rod	0.87	0.92	0.74
Screen-Maddox rod		0.89	0.85
Screen and parallax			0.72

B. Lateral heterophoria at thirteen inches

	Maddox rod	Screen-Maddox rod	Screen and parallax
Maddox rod	0.74	0.89	0.70
Screen-Maddox rod		0.82	0.76
Screen and parallax			0.67

The selection of one test over others as the best measure of phoria is possible then, only when the method selected demonstrates clear-cut superiority in respects agreed upon previously as crucial. While the desirable qualities for a valid measure may not have been agreed upon universally, or even achieved, this question must be addressed by those in ophthalmological research. However, for the present needs of the military services, if not for clinicians in civilian practice, it may be assumed that the best test is one in which experimental studies indicate satisfactory sensitivity, a mean and a range which are in agreement with ophthalmological experience, and an adequate reliability or consistency of measurement. In addition, the method of choice should employ the type of ocular innervation which differs least, both in degree and in kind, from that normally employed in binocular fixation. Finally, the preferred method of measuring heterophoria should be at once as simple as possible, and at the same time capable of standardization of administration.

Summary

1. The findings of Beebee, and the results of the experiment which are presented above, recommend the Maddox rod test as a military measure of lateral heterophoria which is as satisfactory as the other two methods. Its advantages are:

A. The consistency of measurement is at least as great as that with the other tests studied.

B. The distribution of scores indicates that small deviations can be elicited over a wide range of measurements.

C. The correspondence between means and variability measures for first and second examinations compares favorably with the correspondence found with two other clinical measures.

D. Standardization of technique can be achieved since the method of administration is simple and there is a minimum of interference by the examiner.

E. The amount of time required for explanation, demonstration and testing is minimal.

2. The reliability of each of the lateral heterophoria measures at twenty feet exceeds its reliability at thirteen inches.

Conclusion

The Maddox rod test is as satisfactory a measure for lateral heterophoria as either the screen-Maddox rod or the screen and parallax tests. Accordingly the Maddox rod test is accepted as a standard clinical measure for evaluating the phoria measures elicited by the visual screening devices studied in Part Two below.

Part 2. COMPARISON OF THE MADDOX ROD TEST FOR LATERAL AND VERTICAL PHORIA WITH PHORIA TESTS INCORPORATED IN THREE VISUAL SCREENING DEVICES

(Keystone "Telebinocular", American Optical "Sight Screener" and Bausch & Lomb "Ortho-Rater")

Introduction

A previous experiment (19) reported before this group at the April 1945 Meeting (20) indicated that visual screening devices might be acceptable for ocular tests in routine physical examinations of military personnel.

The results reported in the first portion of the present experiment are in agreement with those of Captain Scobee - that the Maddox rod test for lateral phoria is an adequate measure of horizontal muscle imbalance. That test takes advantage of the fact that the eyes will superimpose two different uniocular impressions into a single binocular perception. While the screening devices involve heterophoria targets and a method of presentation that are different from those in the Maddox rod test, the basic principle is essentially the same. The similarity is stressed by redefining the concept "heterophoria"; from an operational standpoint, it is the deviation of the eyes which is overcome and rendered latent when fusion is permitted. (21)

Description of Tests

The Maddox rod test displays a light to the left eye and a streak of light to the right eye. On the other hand, the phoria targets in the instrument tests display arrows or lines for one eye and dots or steps for the other eye.

The Ortho-Rater incorporates an additional feature, in that while the right eye views a row of dots in the lateral phoria targets, the left eye is presented with an arrow pointing to the middle one of three horizontal dots. The dots seen by the left eye fuse with those seen by the right eye and thus tend to minimize shifting of the arrow laterally. Minimizing the amount of lateral swing by this means is presumed to make the measure more stable.

Another difference in the instruments lies in the illumination. The Telebinocular targets are illuminated from the front, while the Sight Screener and Ortho-Rater targets are trans-illuminated from behind. In addition, the Sight Screener is unique in that the Polaroid vectograph principle is employed for presenting individual targets to each eye.

Decentered convex lenses are a part of the optical system for the equivalent of the 20 foot distance in each of the instruments. In the Sight Screener, however, the targets for near are viewed at an actual 14 inch distance without the interposition of prismatic lenses.

Procedure

With these points in mind, the study outlined by Comdr. Cook was undertaken. In recapitulation of that paper, 121 individuals were measured without eyeglasses and in strict accordance with the procedure described in the "Manual of Instructions for Testing Heterophoria" (1). This method employs the Maddox rod and differs from that reported in the first part of this paper in that the subject adjusts the Risley prisms of the phorometer himself, and the near target is depressed to a level of 6 inches below the level of the subject's eyes at a distance of 13 inches. This latter change has been recommended in order to approximate the visual axes more closely to the reading position.

For the room used in testing with the Maddox rod, wall brightness was measured by a Macbeth illuminometer at eye level as 0.5 apparent foot candles. Wall brightness around the 20 foot light from the observer's position was 0.2 apparent foot candles.

In measuring lateral heterophoria with the Maddox rod the streak of light is placed on the exophoric side of the zero mark on the Risley prism scale, before the measure is begun. The instructions to the subject were exactly as prescribed in the Manual. One objective of the experiment was, after all, an assessment of a simple method requiring a minimum of instruction and supervision. In most cases the subject rotated the prisms during the course of the measurement without pausing or reversing the direction of movement until he indicated that the end-point had been reached. In some cases, however, a subject would reverse the direction of prism movement spontaneously one or more times before the measurement was completed.

The procedure described in the Bausch & Lomb Ortho-Rater "Standard Practice" manual (22) was followed in using the Ortho-Rater. However, since the Sight Screener procedure measures the extreme of excursion as a measure of lateral heterophoria, a similar procedure was adopted arbitrarily with one Ortho-Rater for purposes of comparison. A second Ortho-Rater was studied, and in using this instrument only the standard procedure was followed.

In the Telebinocular tests, the subject read the values at which the indicator came to rest. It was assumed that any error of phoria measurement inherent in the optical system

of the instruments would be maximal for subjects with extremes of interpupillary distance, especially for measurements at the near point. (25) Accordingly, the data for near lateral phoria were divided according to the subjects' interpupillary distance as determined by five measures using an N.D.R.C. interpupillometer. (19)

Finally, an effort was made to determine correlation between heterophoria and age.

Results:

Table III presents the reliability coefficients for the four Maddox rod tests. Shown also are reliability coefficients for each of the several tests under consideration, and coefficients between instrument tests and the corresponding clinical measure.

Discussion

Statistical analysis of the data is complicated by the fact that, with the exception of the Telebinocular slide for lateral imbalances, the scale units on the phoria targets supplied with each instrument are designated by arbitrary code digits. For each code the manufacturer of the device supplies a conversion key which is adequate for clinical purposes.

However, there is no certainty as to whether the conversion values for phoria score interval limits should be assigned to the mid-points or to the limits of the scale units. Until details of the scale conversions are available, one is not justified in converting arbitrary instrument score values into prism diopters. In this paper no decoded instrument values are presented.

A comparison of the results from the Maddox rod far lateral phoria measures suggests that a procedure wherein the examiner adjusts the prisms is more reliable than a procedure wherein the subject makes his own adjustment. Note that a more involved situation obtains in the Maddox rod near lateral phoria measurement. Not only is there an operator difference but the viewing angle is different. When the angle of view is made to conform to the reading position and the subject makes his own adjustment, the reliability is higher than when a trained observer makes the adjustment for the target at the level of the subject's eyes. The viewing angle is evidently critical and it is believed that the reliability of the Maddox rod measurement at near, and using the reading position, would be even higher than 0.87 if a trained operator adjusted the prisms.

The reliability and validity data for phorias in Table III merit extended discussion.

(1) Each of the near lateral reliability coefficients is higher than the corresponding value for far. The opposite had been expected on the basis of the results of the experiment described in the first part of this paper. However, as noted in the paragraph above, the viewing angle difference is probably important enough to account for the higher reliability at the position used in reading.

(2) The Maddox rod reliability coefficients for lateral phoria at 20 feet and at 13 inches are significantly higher than the inter-correlation coefficient between the far and near measures. A similar finding by use of the Ortho-Rater has been reported. (19)

(3) The inter-correlation data for the instruments versus the criterion Maddox rod test are not as high as the reliability coefficients for either the instruments or the Maddox rod test. It is possible that the instruments are not measuring the identical functions determined by the Maddox rod measure. Verhoeff (14) has made a statement quoted in the first part of this paper that for tests by use of a stereoscopic device "the observer has no accurate idea of the distances concerned". At least the observer has a feeling of nearness of the targets when using screening devices and this attitude may influence, by association, the impulse to accommodate.

(4) In general, the lateral phoria measures elicited by the instruments correlate slightly higher with the Maddox rod lateral phoria equivalents than do the corresponding values for the vertical measures.

(5) The comparison of two procedures in administering the lateral phoria test by the Ortho-Rater indicates that the standard procedure is more consistent than the so-called "excursion" procedure. Two different Ortho-Raters with standard procedure elicit nearly identical data for means and standard deviations for distance and near.

(6) No correlation of phoria scores with interpupillary distance is noted. From the IPD analysis for this small population, it happened that the group with narrow IPD was slightly more exophoric (0.06 standard deviation units from the total group mean); the middle IPD group was slightly more esophoric (0.12 standard deviation units from the total group average); the wide IPD group was also more exophoric (0.09 standard deviation units from the total group mean). These differences in Maddox rod scores are probably insignificant.

(7) The data show no meaningful correlation between age and phoria measures. The correlation coefficients tended to be magnified with the oldest group, but this can be attributed to the enhanced variability of the scores from the oldest group.

Table III
Phoria Reliability and Validity Data

	Maddox rod				Ortho-Rater				Sight Screener				Telebinocular		
	Lateral		Vertical		Lateral		Vertical		Lateral		Vertical		Lateral		Vertical
	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near	Far	Near	Far
Maddox rod															
Lateral															
Far	.793	.668	.151	.173	.564				.370				.371		
Near		.867	.155	.159		.674				.543				.683	
Vertical															
Far			.623	.446			.286				.279				.426
Near				.677				.343				.337			
Ortho-Rater															
Lateral															
Far					.872										
Near						.924									
Vertical															
Far							.630								
Near								.624							
Sight Screener															
Lateral															
Far									.796						
Near										.831					
Vertical															
Far											.613				
Near												.551			
Telebinocular															
Lateral															
Far N													.755		
Near														.880	
Vertical															
Far															.602

Summary

(1) Certain criteria for a valid measure of heterophoria are presented.

(2) The Maddox rod test meets these criteria, at least for lateral phoria, as well as the screen-Maddox rod or the screen and parallax tests.

(3) Three visual screening devices were used to measure heterophoria and the results are compared with the data from the Maddox rod test. The data from the latter experiment indicate:

(A) That visual screening devices are apparently as reliable as the clinical method for the measurement of phoria.

(B) That the instrument tests do not correlate well with the clinical test; it is possible that this is due to some defect in construction of the devices or in the method of measurement.

(C) That further research is indicated to establish why there is no more correspondence between the clinical and the instrument measures.

(4) No significant correlation between heterophoria and either interpupillary distance or age grouping is noted.

BIBLIOGRAPHY

(1) "Heterophoria Testing Manual of Instructions" (Restricted) developed by the Subcommittee on Procedures and Standards for Visual Examinations of the Army-Navy-OSRD Vision Committee, 1945.

(2) "A Bibliography of Visual Literature, 1939-1944, and Supplement" (Secret). Publication No. 11, Historical Library, Yale Medical Library, 1945.

(3) "Relationship of Interpupillary Distance to Performance on the Ortho-Rater" Sulzman, J. H., Minutes and Proceedings of the Army-Navy-OSRD Vision Committee (Restricted) Twelfth Meeting - 12 June 1945, Washington, D. C.

(4) "Testing Vergence and Phoria" Scobee, R. G., Minutes and Proceedings of the Army-Navy-OSRD Vision Committee (Restricted) Fourteenth Meeting - 11-12 September 1945, New London, Conn.

(5) "The Measurement of Heterophoria" Cridland, N., British Jour. Ophth., Vol. 25, No. 5 (May) 1941.

(6) "Objective Strabismometry in Young Children" Wheeler, M. C., Arch. Ophth., Vol. 29, No. 5 (May) 1943.

(7) "Motor Anomalies of the Eye, The Relative Value of the Tests Used in Diagnosing Them" Duane, A., N. Y. Med. Jour., Vol. 99, No. 9 (February) 1914.

(8) "The Extra-Ocular Muscles" Peter, L. C., Third Ed., pub. Lea and Febiger, Philadelphia, 1941.

(9) "Detecting, Measuring, Plotting and Interpreting Ocular Deviations" Lancaster, W. B., Arch. Ophth., Vol. 22, No. 5 (November) 1939.

(10) "Routine Muscle Examination in its Practical Application" White, J. W., Trans. Sect. Ophth., A. M. A., 1934.

(11) "The Screen Test and its Modifications" White, J. W., Penn. Med. Jour., (September) 1936.

(12) "Routine Examinations of the Ocular Muscles and Non-operative Treatment" Berens, C., Losey, R. L., and Hardy, L. H., Am. Jour. Ophth., Vol. 10, No. 12 (December) 1927.

(13) "Approach to the Phorias" Livingston, P. C., British Orthop. Jour., 1:71-104, 1939.

(14) "Heterophoria Tests Based on a New Principle" Verhoeff, F. H., Arch. Ophth., Vol. 22, No. 5 (November) 1939.

(15) "Manual of Ocular Tests" pub. Council on Education and Professional Guidance, Am. Optom. Assoc., 1944.

(16) "The Maddox Rod and Screen Test Combined" Dolman, P., Air Service Inf. Circ., 1:42 (August 15) 1920.

(17) "A Tentative Interpretation of the Findings of the Prolonged Occlusion Test on an Evolutionary Basis" Marlow, F. W., Arch. Ophth., 19:194 (February) 1938.

(18) "Lectures on Motor Anomalies" Bielschowsky, A., pub. Dartmouth College Publications, Hanover, N. H., 1940.

(19) "Comparison of Various Screening Devices with Standard Medical Visual Procedure" Progress Report No. 1. on BuMed Research Div. Project X-493, Medical Research Dept., U. S. Submarine Base, New London, Conn., 22 November 1945.

(20) "Comparison of Five Methods of Screening for Acuity and Muscle Balance" Sulzman, J. H., Farnsworth, D., Bartlett, N. and Kindred, M. I., Minutes and Proceedings of the Army-Navy-OSRD Vision Committee, Eleventh Meeting - 10 April 1945, Washington, D. C.

(21) "Terminology in Ocular Motility" Lancaster, W. B., Am. Jour. Ophth., Vol. 26, No. 2 (February) 1943.

(22) "Standard Practice in the Administration of the Bausch & Lomb Occupational Vision Tests with the Ortho-Rater" pub. Bausch & Lomb Optical Co., Rochester, N. Y., 1944.

(23) "Near Horizontal Phoria and Duction Tests" Abraham, S. V., Am. Jour. Ophth., Vol. 26, No. 3 (March) 1943.

Discussion:

Dr. Miles requested information concerning the line of regard in various tests of phoria.

Lt. Comdr. Sulzman reported that in the Ortho-Rater, examinees depressed the line of regard slightly for the far test and depressed still further for the near test compared with the

normal line of regard used in the acuity tests on this instrument. In the Telebinocular, the line of regard is the same for all tests of acuity and phoria. In the Sight Screener, line of regard is directed normally for the near test of phoria but is depressed for the far test of phoria.

Dr. Scobee emphasized that the line of regard is an important variable in phoria measurements since phoria is actually introduced by deviations from the normal line of regard.

Dr. Berens asked how long the Maddox rod was allowed to remain in the subject's field of view before measurements were made.

Lt. Comdr. Sulzman replied that records were available for all tests and that the average time was one to two minutes. He reported that patients often develop deviation after continual observation of the Maddox rod.

Dr. Scobee traced the history of heterophoria measurements briefly and emphasized the value of the work done by Lt. Comdr. Sulzman. He emphasized the great confusion in the literature of heterophoria measurements which was at least partially attributable to the large number of tests of phoria which had never been properly compared.

Capt. Shilling inquired whether information resulting from Lt. Comdr. Sulzman's investigation necessitated changing the Manual of Instructions, Testing Heterophoria, previously prepared by the Vision Committee.

Dr. Vail, Chairman of the subcommittee responsible for developing this manual, replied that Lt. Comdr. Sulzman's data indicated that the examiner rather than the examinee should be permitted to adjust the prisms.

VOTED: (1) that the manual of instructions, Testing Heterophoria, prepared by the Subcommittee on Standards and Methods of Visual Examination, be accepted with the following amendment:

that the adjustment of the prisms in phoria measurement be made by the examiner instead of the examinee.

(2) that the amended manual of instructions, Testing Heterophoria, be forwarded to the appropriate offices of the Army and Navy with the recommendation that it be adopted for use by the armed services inasmuch as it represents the consensus on heterophoria in the light of present knowledge. Should subsequent investigations uncover better methods of testing, suggested revisions of the Manual will be forwarded.

MANUAL OF INSTRUCTIONS

TESTING HETEROPHORIA

This manual was prepared by

Richard G. Scobee, M.D.

for the Subcommittee on Procedures
and Standards for Visual Examinations,
Army-Navy-OSRD Vision Committee

TESTING HETEROPHORIA
MANUAL OF INSTRUCTIONS

TESTING HETEROPHORIA
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A. THE PROBLEM OF TESTING HETEROPHORIA

Heterophoria is a condition in which the eyes have a constant tendency to deviate but are prevented from so doing by a process of FUSION. When a person looks at an object, an image of that object is formed seperately in both the right and the left eye. These separate images are sent to the brain where they are associated and interpreted as a single image; this process is known as fusion. The fusion process is responsible for the two eyes working together in harmony and when anything prevents this, fusion is disrupted and one eye deviates. Since heterophoria is only a tendency of the eyes to deviate, no actual deviation is apparent. The deviation becomes visible only when fusion control is weakened or abolished. When deviation occurs, its exact amount can be estimated with some accuracy by neutralizing the deviation with prisms of varying strength. If the deviating eye turns in (toward its fellow), the deviation is known as esophoria; if it turns out (away from its fellow), the deviation is known as exophoria; if the deviating eye turns up or down, the deviation is called hyperphoria or hypophoria, respectively.

1. BREAKING UP FUSION. For the purpose of heterophoria measurement, fusion can be disrupted by placing a Maddox rod in front of one eye. The image of a spot of light, when viewed through a Maddox rod, is converted into a line of light. When the two eyes see unlike images of the same object (one eye sees a spot of light while the other eye, the one behind the Maddox rod, sees a line of light), this disrupts fusion and tends to prevent the two eyes from working together, thus, when heterophoria is present, one eye (the eye behind the Maddox rod) will deviate when its fellow eye continues to look at or fixate the spot of light.

2. STANDARDIZATION OF THE TEST. The measurement of heterophoria is one of the most difficult problems that the inexperienced examiner can meet. The reason is simple. There are many factors which influence the test and only a few of these are actually known. For example, it is just as important to have the examinee seated comfortably during the test so that his neck muscles are not strained as it is to have the testing equipment in good condition. Strained positions of the head and neck have a definite effect upon the measurement of heterophoria. Unless the test is performed in exactly the same way at every testing station, an examinee may pass the test at one station on one day and fail it on the next day at another station. A UNIFORMLY STANDARDIZED TESTING TECHNIQUE

MUST BE USED AT EVERY STATION. This manual has for its purpose the description of the testing technique to be followed at all testing stations.

B. NECESSARY EQUIPMENT

1. A testing room long enough to provide a distance of 20 feet between the muscle light and the eyes of the seated examinee.

2. A comfortable testing chair located at one end of the room.

3. A muscle light (spot of light) 1 centimeter in diameter, placed at a distance of 20 feet from the eyes of the seated examinee and facing him.

4. An ophthalmoscope with a removable, May-type head.

5. Either: (a) A binocular phorometer with Risley rotary prisms, white Maddox rods, and Stevens phorometer (graduated in tenths of a prism diopter from 0 to 2.0) attached.

Or: (b) A monocular, portable phorometer with a Risley rotary prism and white Maddox rod attached.

Or: (c) A trial frame with a white Maddox rod and graduated and accurately calibrated prisms, either loose or arranged vertically in a prism bar.

6. Some method of measuring exactly 13 inches from the front of the phorometer. A cord tied to the phorometer and either looped or knotted at the proper length is satisfactory. Some phorometers have a metal rod attached to which a small light may be fixed in order to accurately measure heterophoria at 13 inches.

C. TESTING WITH THE BINOCULAR PHOROMETER

1. SEATING THE EXAMINEE. The examinee should first be comfortably seated in a chair. A straight backed chair with arms is preferable to a stool. If there is a head rest on the chair, it should be accurately and comfortably adjusted.

2. ADJUSTING THE PHOROMETER. The phorometer should be carefully adjusted to the examinee -- NOT the examinee to the phorometer. He should never be told to "come forward a little," to "stretch your neck a bit," or "move your head sideways (to right or left) a little bit." The examiner must make these adjustments himself with the various controls on the phorometer; that is why they are there. DON'T MAKE THE EXAMINEE ADJUST HIMSELF TO THE PHOROMETER. Adjusting the phorometer means several things. It means:

(a) Having the entire length of the brow-piece touching the examinee's forehead and exerting gentle but firm pressure.

(b) Having the bubble in the spirit level accurately centered between the two markers.

(c) Having the interpupillary distance reading set on the scale and the phorometer high enough so that each of the examinee's pupils is exactly centered behind its respective frame.

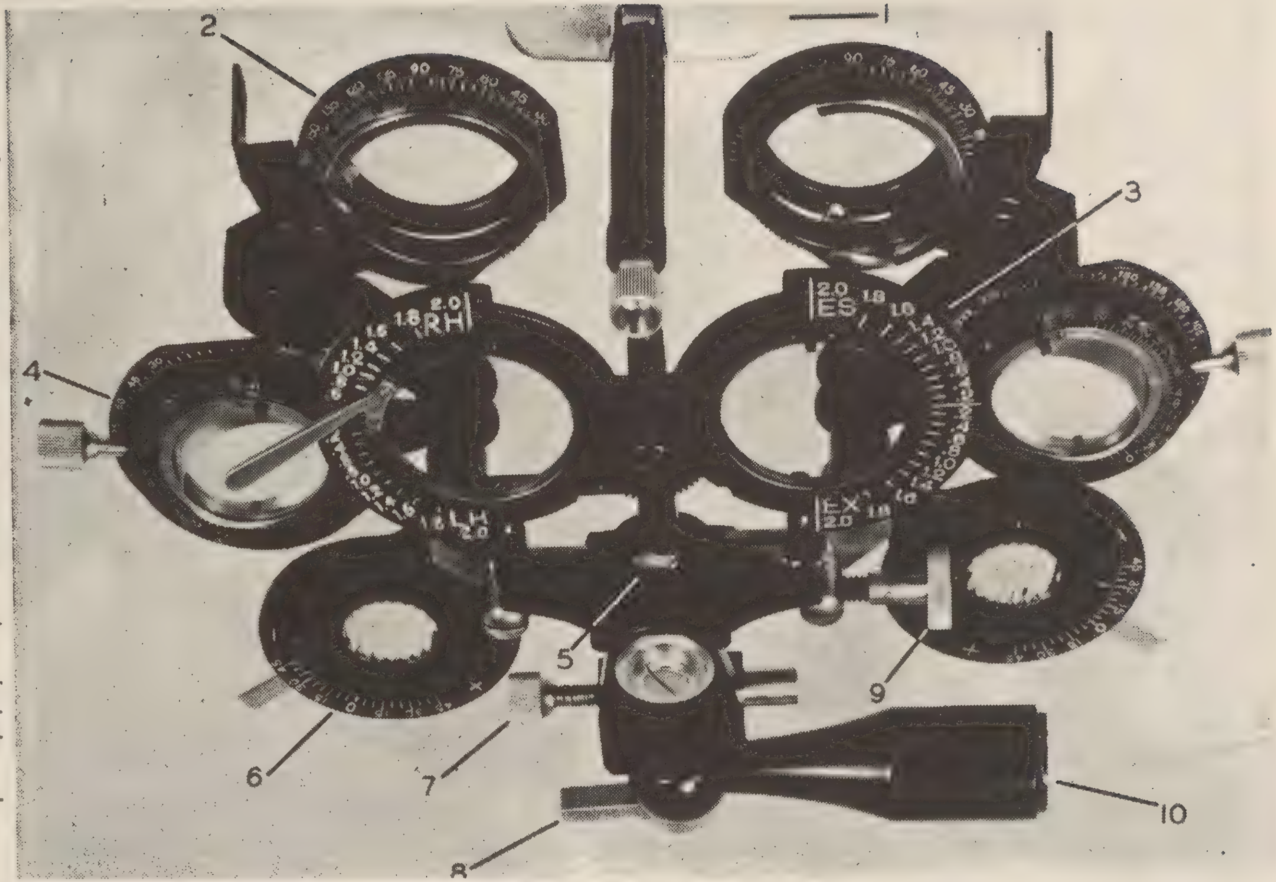
(d) Having the examinee so seated and the phorometer so placed that both are exactly and directly facing the muscle light across the room.

(e) The examinee's glasses. If the examinee wears glasses all the time, any test of heterophoria should be made with his glasses in place. This may be accomplished in one of two ways. The less accurate method is to have the examinee wear his glasses and adjust the phorometer eyepieces so that they touch his glasses and so that they are accurately centered before the lens of each eye. A much better and more accurate method, <u>if</u> the prescription for glasses which the examinee is wearing <u>is</u> known, is to select the proper lenses which make up his prescription from the trial case and insert them into the cells in the trial frame on the phorometer (2 in the photograph of the phorometer). If the examinee wears glasses all the time, any measurement of his heterophoria without his glasses is utterly worthless and entirely undependable.

3. THE MADDOX ROD. The examinee's attention is directed to the muscle light which is a spot of light 1 cm. in diameter located at a distance of 20 feet across the room. To insure his seeing it, the examiner should flash it on and off a time or two by means of a remote control switch located conveniently near at hand, if this is available. There must be no other sources of light except the muscle light visible to the examinee. There may be other lights in the room as long as the examinee cannot see them. All reflecting surfaces should also be removed from the examinee's range of vision. If this is not done, the overhead light which the examinee cannot see directly may nevertheless be reflected into his eyes from any shiny metal or glass objects in the room. If this reflection occurs, more than a single line is liable to be seen through the Maddox rod and will prove to be a disturbing factor if not a source of actual error in the test. Once the examinee has definitely located the muscle light, a white multiple Maddox rod attached to the phorometer should be rotated into position. This means rotating it on its hinge as far as it will go. It should be placed before the RIGHT EYE. The axes of the small rods which make up the multiple Maddox rod should be in the horizontal meridian. With the rod in this position, when the examinee looks at the muscle

The PHOROMETER

1. Adjustable fore-head rest.
2. Triple cell trial frame with degree markings for cylinder axes.
3. Stevens phorometer or frame
4. Risley rotary prism.
5. Bubble level.
6. Multiple or compound Maddox rod.
7. Thumb screw for leveling phorometer.
8. Near work attachment socket.
9. Thumb screw for adjusting to interpupilary distance.
10. Socket for supporting rod.



light, he sees a vertical white line with his right eye (which has the Maddox rod in front of it) and a spot of light with his left eye. He is thus seeing unlike images of the same object, i.e., the spot of light.

The examinee should now be specifically questioned as to whether he sees both a vertical white line of light and a white spot of light. If he does, the testing may proceed. If he does not see both the line and light at the same time, one of several things may have happened:

(a) The phorometer frames may not be exactly centered before each eye.

(b) Although properly centered, the phorometer may not be aimed exactly at the light.

(c) The examinee may have closed one eye. BOTH EYES MUST BE KEPT OPEN AT ALL TIMES DURING THE TEST.

(d) The examinee may be unconsciously suppressing vision in one eye (see paragraph 4, below).

(e) Visual acuity may be poor in one eye.

(f) One eye may be turned far in or far out; if one eye is deviating a great deal ("cross-eyed" or "wall-eyed"), this fact should have been noted on external examination. The presence of a manifest deviation is known as heterotropia, and no heterophoria measurement is accurate or is usually even possible in such cases.

4. SUPPRESSION. Double vision is usually avoided by the natural impulse to line up the two eyes so that they work together. In the presence of heterophoria, the examinee fuses the two images into one but to do this requires effort (whether he is aware of it or not). If the required effort is too great, one of the two images may be ignored by the brain and when this happens, it is known as suppression. In the case of the Maddox rod test, it is somewhat annoying to look at a spot of light, yet see a line of light with one eye and a spot of light with the other. The image of the line is often suppressed (ignored) by the brain, which means that it seems to fade in brightness and may disappear entirely.

If the examinee sees only the line, or only the light, or the line and then the light alternately, it may be assumed that he is suppressing, provided:

(a) The phorometer is properly adjusted.

(b) Visual acuity is normal or anywhere near equal in the two eyes.

(c) There is no gross deviation of the eyes on external examination (inspection).

If the examinee sees only the spot of the light (using his left eye), the left eyepiece of the phorometer should be covered with an occluder until the line is seen by the right eye. If the cover is then removed, the line and light will usually be seen simultaneously. Likewise, if only the line is seen (using the right eye, which has the Maddox rod in front of it), the occluder should be placed over the right eyepiece of the phorometer until the spot of light is seen by the left eye. It may then be removed.

5. THE RISLEY ROTARY PRISM. Once the examinee sees the line and light simultaneously, the next step is the removal of the Maddox rod from its position before the eye and the rotation of the Risley rotary prism attached to the phorometer into position before the right eye. It will be noted that its location is behind the Maddox rod, between the Maddox rod and the examinee's eye. The handle of the rotary prism should be rotated into the vertical position (at 90°). By means of this same handle, the line indicating the position of the prism base should be rotated on or near zero. Some of the older phorometers have the handle so placed that it is to one side when horizontal muscle balance is being tested. Others have it at an angle. The proper position should be determined by the examiner beforehand.

(a) Marking the prism. It is a difficult problem for the inexperienced examiner to remember whether prism base in indicates exophoria, prism base down hyperphoria, etc. For this reason, a very simple and practical solution may be found in the use of a little adhesive tape. One piece should be stuck on the fixed frame of the rotary prism over the 90° mark, and another over the 180° mark on the right eyepiece and over the 0° mark on the left eyepiece. With pen and ink, a line representing the three marks which have been covered should be drawn. See figure 1. On the tape over the 90° on the prism before the right eye, the letter "X" should be printed on the tape on the side of the line toward the nose; similarly, a letter "S" may be printed on the opposite side of the line (toward the temple). When heterophoria is being measured, if the prism base marker is set on the "X" side of the 90° mark, EXOPHORIA is present (prism base in); if the marker has been set on the "S" side, ESOPHORIA is present (prism base out).

In the same manner, the tape at 180° and at 0° can be lined. Above the line on the right prism, print the letter "L" and below the line the letter "R". When vertical heterophoria is being tested and the rotary prism handle is set at 180o (right eye), if the prism marker has been set above the line (in the "L" area), then LEFT HYPERPHORIA is present. If

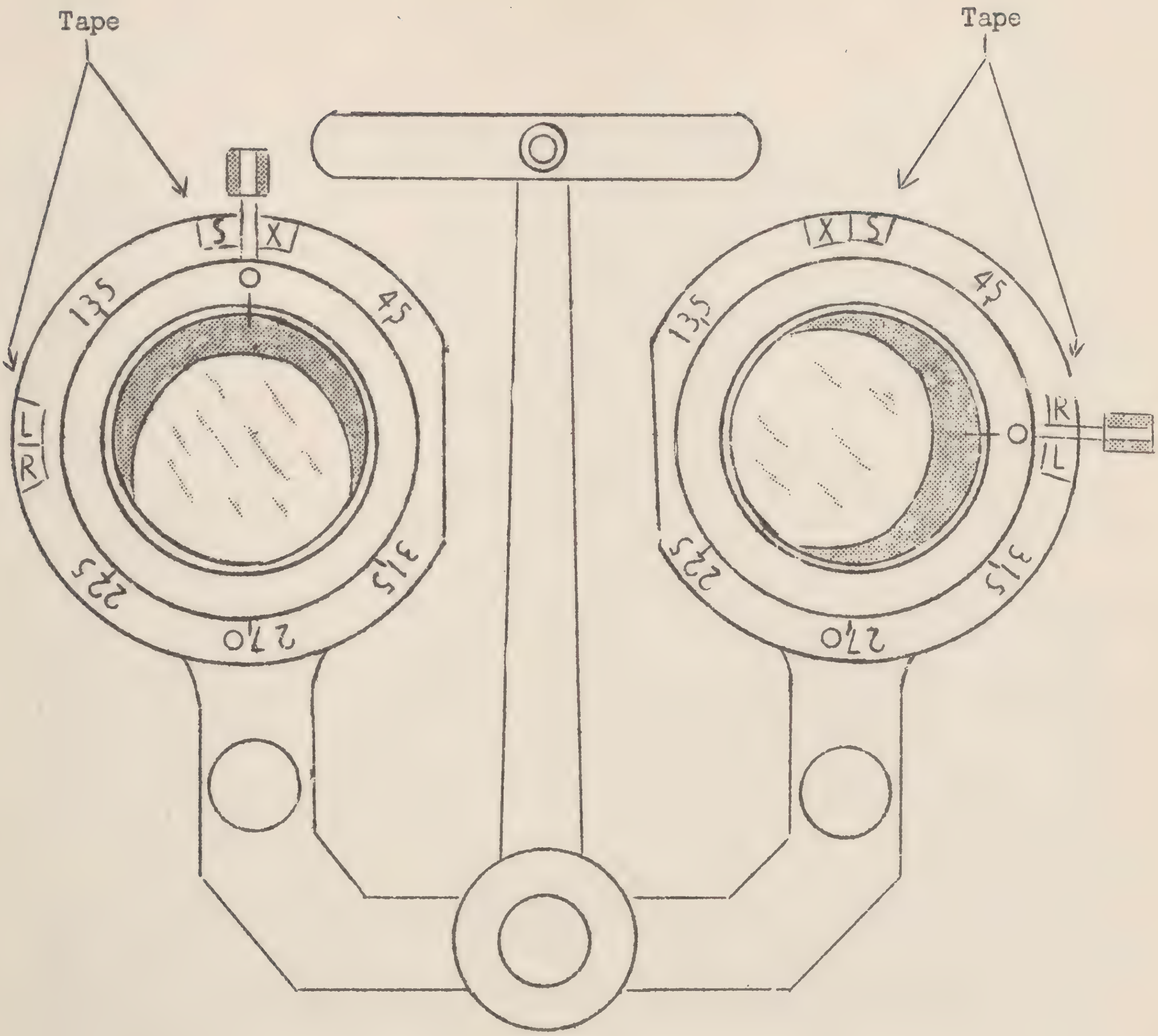


Figure 1.

FRONT VIEW OF PHOROMETER (Maddox rods removed)

the marker has been set below the line (in the "R" area), then RIGHT HYPERPHORIA is present. This is true for the right eye. For the left eye, as is shown in the diagram, all markings are reversed.

(b) Instructions to the examinee. Having assured himself that the examinee sees both the line of light (seen through the Maddox rod) and the spot of light, the examiner is ready to begin the test. Since the examiner adjusts the Risley prism, the examinee need only be instructed to tell the examiner when the line of light runs right through or bisects the spot of light. The instructions would therefore be something like this: "I am going to move the line. I want to adjust it so that it runs right through the center of the spot of light." The examiner then slowly turns the knob controlling the Risley prism in one direction or the other, meanwhile asking, "Is the line moving toward the light or away from it?" If the examinee replies that the line is moving away from the light, the examiner immediately begins turning the Risley prism control knob in the opposite direction, meanwhile asking, "Now is the line going toward the light?" When the examinee indicates that the line is moving toward the light, the examiner continues to turn slowly, saying, "Now when the line runs through the exact center of the light, tell me to stop." When the examinee states that the line is running through the center of the light, the Maddox rod is rotated out of position in order that the calibrated scale on the Risley prism may be easily read. The scale reading is recorded.

The examinee may often state in one breath that the line is running through the light and in the next breath state that this is no longer the case. The examiner should reassure him by telling him that it often happens and continue adjusting the prism until the line stops moving and an accurate reading can be made.

6. THE MADDOX ROD TEST AT 20 FEET.

(a) Lateral heterophoria.

The examiner should always begin the test with the Risley prism set "off" of zero in one direction or the other, preferably on the "X" side (exophoria) so that some adjustment will have to be made in every case.

When the reading is completed, if lateral heterophoria was being measured, then if the prism marker is on the side of the line toward the examinee's nose (in the "X" area), exophoria is present; if on the side toward the examinee's temple (in the "S" area), esophoria is present.

(1) Doubtful cases. If any doubt exists in the mind of the examiner about the results of the test, the Maddox rod and rotary prism before the examinee's right eye should be rotated out of position and the rod and prism on the other side of the phorometer rotated into position before the left eye. The procedure described previously should then be repeated. If there is a great difference between the readings with the Maddox rod before the right eye and before the left eye, both should be repeated again. If there is only a small difference, i.e., 2 or 3 prism diopters, the LARGER of the two should be recorded as the lateral heterophoria (esophoria or exophoria as the case may be) for the examinee. A consistently large difference between the readings for the right and left eye indicates a partial paralysis of one of the extraocular muscles and calls for a repeated examination of the extraocular movements and a red lens test with charting of diplopia fields.

(b) Vertical heterophoria. When the lateral heterophoria has been tested, the next step is the measurement of vertical heterophoria. With the Maddox rod before the right eye, the rod should be adjusted so that the axes of its component glass rods are in the vertical. The eye behind the rod now will see the spot of light as a horizontal line. The Risley prism is turned down and out of position and the Steven's Phorometer is turned up into its vertical position. Set the index of the Steven's Phorometer at 2.00 LH (Left Hyperphoria). The examinee is told that he should see a horizontal line below the spot of light. The examiner grasps the controlling lever of the Steven's Phorometer and moves the lever up slowly until the examinee states that the line bisects the spot of light. If the examinee reports that he also sees another spot of light he is told to ignore the faint spot and to watch the line until it bisects the bright spot. When this is done the examiner reads the scale in tenths of prism diopters of hyperphoria. As indicated on the Steven's Phorometer, if the index is set below the zero position, the measurement is of left hyperphoria (LH), and if it is set above the zero position the measurement is of right hyperphoria (RH). When testing the left eye, the relative positions of the line and spot of light are reversed. That is, with the index set at 2.0 LH (Left Hyperphoria) the line will appear to the examinee to be above the spot of light.

ONLY HYPERPHORIA IS RECORDED. It has been previously stated that the eyes may deviate upward (hyperphoria) or downward (hypophoria). In most cases, when one eye turns up, its fellow eye tends to turn down. For simplification, only hyperphoria is recorded. Thus, if the right eye tends to turn upward, it is right hyperphoria. If the right eye tends to turn downward, the left eye would tend to turn upward in the majority of cases and so left hyperphoria would be recorded. The proper finding, whether the Maddox rod is before the right or left eye, is always indicated on the Steven's Phorometer by the letters RH or LH for right or left hyperphoria respectively.

(1) Doubtful cases. If there is any doubt about the measurement in the mind of the examiner, the left eye should be tested in a similar fashion. This is done by placing the Maddox rod before the left eye instead of the right eye and by using the Steven's Phorometer as described above. The only apparent change is the reversal of the relative positions of the line and the spot of light at the beginning of the test. A difference of more than 0.5 prism diopters between the right and left eye measurements should be the cause for a recheck of the hyperphoria measurements for each eye. In this case it would be well to begin the test with the index set at 2.0 RH (Right Hyperphoria). The examiner moving the line in the opposite direction as described above until the line bisects the spot of light. The averages for the settings "from below" and "from above" when the Maddox rod is before the right and the left eyes should be compared. If the difference is greater than 1.0 prism diopter there is, in all probability, a slight paralysis of one or more of the extraocular muscles and a red lens test with the charting of the diplopia fields is indicated.

(2) Cases with more than 2.0 prism diopters of hyperphoria. Occasionally an examinee may have more than this amount of hyperphoria. This will be indicated at the beginning of the test by the examinee reporting that the line appears above the spot of light instead of below when the index of the Steven's Phorometer is set at 2.0 LH. Remove the Steven's Phorometer and place the Risley prism in position with its handle in the horizontal and toward the examinee's temple. The line is then adjusted so that it runs through or bisects the spot of light. When this is done, set the index of the Risley to the nearest whole division toward zero and bring the Steven's Phorometer into position. Now adjust the lever of this Phorometer until the line bisects the spot of light. The sum of the readings on the Risley and the Steven's Phorometer gives the total hyperphoria, and the position of the index of the Steven's Phorometer indicates whether it is right or left hyperphoria that has been measured.

7. THE MADDOX ROD TEST AT 13 INCHES. When the test has been completed at the 20 foot testing distance, the muscle light is turned off. The test should then be performed at 13 inches, using an ophthalmoscope with its head removed at the muscle light. The light should be held exactly in the midline and 6 inches below the level of the examinee's eyes; thus the eyes are in the reading position. It may be necessary to lower the phorometer slightly in order to keep the eyes accurately centered. The light should be held at a distance of exactly 13 inches from the phorometer. A string tied to the center bar of the phorometer and looped at 13 inches will serve nicely. If the ophthalmoscope neck is slipped into the loop and the cord drawn taut, the light will be exactly 13 inches from the phorometer each time the test is performed.

The technique of testing lateral and vertical heterophoria at 13 inches is exactly the same as that used at 20 feet. Occasionally the examinee may complain that he sees more than one line at the 13 inch distance. If the source of this annoying reflex cannot be found, he should be instructed to pay attention only to the brightest line while it is adjusted so that it runs through or bisects the spot of light.

D. TESTING WITH THE MONOCULAR, PORTABLE PHOROMETER

The principle of measuring heterophoria with a Maddox rod and prisms may be applied in several different ways. Because the equipment available for the test varies from one station to the next, two additional testing methods will be described. At some installations there may not be a binocular phorometer available; instead, there may be only the monocular, portable type. This consists of a stick which has an eyepiece mounted at one end in a fixed position. Rotating on an axle attached to the eyepiece are a Risley rotary prism and a white Maddox rod. The instrument is held in position by the examinee and the test is carried out exactly as has been previously described. It is the responsibility of the examiner to make certain that the instrument is held in the proper position at all times during the test. If the right eye is being tested, the examinee should hold the instrument, with its handle vertical, before the right eye with his left hand. The examiner adjusts the prism as before.

E. TESTING WITH A TRIAL FRAME & LOOSE PRISMS

If no phorometer is available, a trial frame should be carefully adjusted on the examinee's eyes. A white Maddox rod from the trial case is placed in the cell before the right eye; its component rods should be placed with their axes horizontal if lateral heterophoria is to be tested first. Once the examinee has located both the line and the light, the examiner should select a weak prism and hold it before the Maddox rod with its base either in or out. Care must be taken to keep the base of the prism exactly vertical if lateral heterophoria is being tested or exactly horizontal if vertical heterophoria is being tested. Several prisms will probably need to be tried (both base in and base out) before one is found which causes the line to run through or bisect the spot of light. The rest of the procedure should be carried out exactly as has been described previously.

F. CHECKING THE MADDOX ROD

Two defects may occasionally be found in a Maddox rod: (a) the line of light may be indistinct rather than sharp, and (b) there may be a prism effect which acts to deflect the line of light from its true position. A Maddox rod which is found to have either of these defects should be

discarded. If the line of light formed by the rod is sharp and clear, any prism can be readily detected by holding the rod before one eye so that a horizontal line of light is seen while the other eye sees a spot of light. The position of the line in relation to the light is observed. The rod is then rotated through a full 180° and the line and light relationship observed again. If no prism is present, the relationship should be identical in the two observation positions described.

G. CHECKING PRISMS

If a phorometer with a Risley rotary prism attached is not available for heterophoria testing, it will be necessary to use loose prisms. These may be available either in a trial case or in a special box (prism set). The strength of each prism should be etched upon the prism itself in units of prism diopters, this prismatic unit being the one used throughout the armed forces. Unfortunately, not all prisms are marked in these units, some are not marked at all, and still others are marked incorrectly. It therefore becomes necessary to check the strength of each prism before it is used in the measurement of heterophoria. This can be very easily and very simply done.

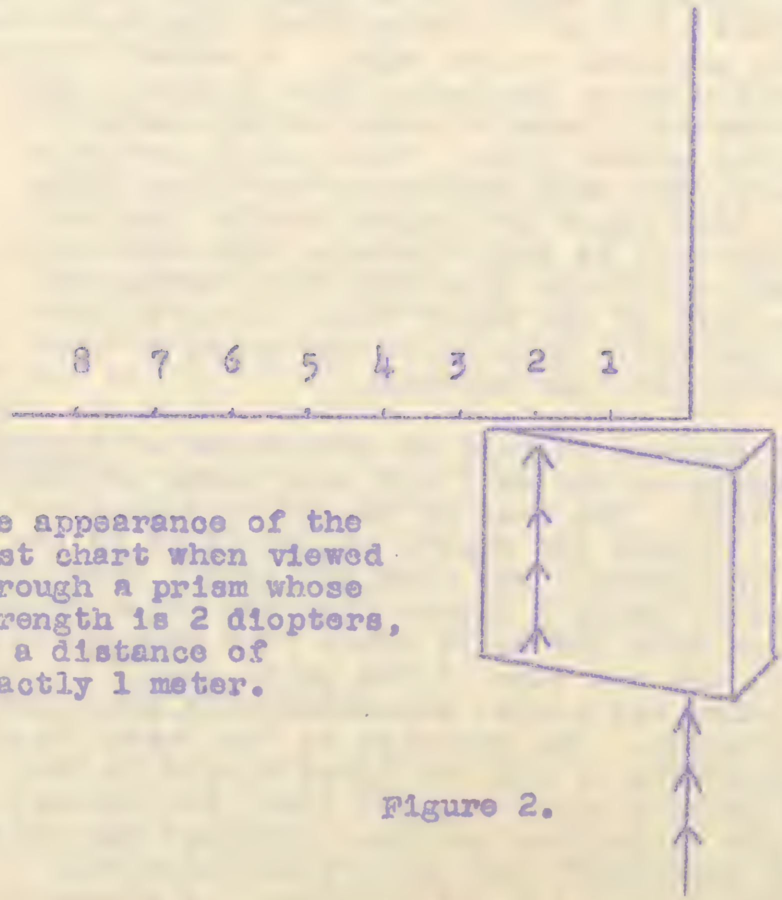
A diagram (see figure 2, page 17) is made on a white sheet of paper 8½ x 11 inches in size. A heavy black line is drawn about 1 inch from and parallel to one edge. A second, lighter line is drawn perpendicular to the heavy line in such a way that it roughly bisects it. Using a meter stick, units of 1 cm. are laid off on the second line. These units should be numbered consecutively, the mark closest to the heavy line being numbered "1". This chart or diagram should then be tacked in place on the wall in such a manner that the heavy black line is vertical while the line with the centimeter markings runs to the left of the heavy line. A series of arrowheads added to the heavy line below the point of the intersection will facilitate the checking.

The prism to be checked is held at a distance of exactly 1 meter from the diagram on the wall and in a plane parallel to the plane of the wall. The base of the prism should be held in the vertical, toward the right, and parallel to the heavy black line on the chart. The examiner should then place his eye at a distance of about 4 inches from the prism in such a position that he can view the heavy black line through it. As shown in figure 2, the top edge of the prism should be held so that it is just below but almost coincides with the lighter marked line on the diagram. The position of the heavy black line above the intersection of the two lines should be such that it strikes the prism's upper edge at about its center. If the left eye is now closed and one looks through the prism, held in the position described, the heavy black line will appear to break at the prism edge and continue its downward

course in a position to the left of its original one. The centimeter marking to which the arrowheads on the displaced portion of the heavy line point is a measurement of the strength of the prism in diopters. If the arrowheads point to a spot between two markings, the appropriate fraction can be easily estimated. If the test is carried out as described and the displaced portion of the heavy line intersects the marked line at 3, for example, then the prism being tested has a strength of 3 diopters. If the displaced portion intersects the marked line at 5, it is a 5 diopter prism, etc.

Two things must always be known about a prism: (a) its strength in prism diopters, and (b) the position of its base. In testing heterophoria, the prism base is placed in the following positions:

1. For exophoria, prism base in (toward the nose).
2. For esophoria, prism base out (toward the temple).
3. For hyperphoria, prism base down (toward the cheek).
4. For hypophoria, prism base up (toward the eyebrow).



The appearance of the test chart when viewed through a prism whose strength is 2 diopters, at a distance of exactly 1 meter.

Figure 2.

A STUDY OF ACUITY IN THE MESOPIC BRIGHTNESS RANGE IN RELATION TO REFRACTIVE ERROR

Franklyn D. Burger, M. D.

A preliminary study of civilian airline pilots had shown that a pilot's visual acuity rating when tested at fairly high light levels did not indicate what it would be in the mesopic range and had suggested a screening procedure which would serve in examining large numbers of men. On the basis of this study, the present survey was carried out for the Bureau of Medicine and Surgery of the Navy.

Four hundred and ninety-eight men were examined. The procedure used, consisted of a test of visual acuity at 24 light levels between 0.0027 foot candles and 2.0 foot candles after preliminary dark adaptation. The light on the test chart and that on the man's eye was held at the same level. Following this test, the men were refracted for the highest plus power giving maximum visual acuity when combined with any minus cylinder required by the man's refractive error. Tests were also made of the phorias. The results of these tests were analyzed and graphed by type and amount of refractive error. The resulting charts are in the process of preparation and further correlations are being made.

In general, this survey has shown that, in the light range tested, the best visual acuity is shown by those with a spherical error of three quarters of a diopter of hyperopia. Between three quarters of a diopter and one and three quarters diopters of hyperopia the visual acuity at these low light levels remains about the same and with more than two diopters of hyperopia there is a slight decrease in visual acuity. The number of subjects in the higher values,is, however, too small for significance.

With less than three quarters of a diopter of hyperopia, the average visual acuity in low illumination decreases gradually until emmetropia is reached and then there is an abrupt drop as one quarter diopter of myopia is reached. At extremely low light levels this rapid rate of decrease is maintained to values of myopia as high as one diopter while at intermediate levels of low illumination a plateau is reached at one half diopter of myopia which extends to one diopter and then there is a second abrupt drop in average visual acuity.

The visual acuity under low levels of illumination was found to vary with the amount of hyperopia present (considering

myopia as a negative value of hyperopia). The presence of astigmatism in amounts up to one diopter was found to have but a slight effect on the visual acuity. It was found that if one recorded the visual acuity in terms of plus sphere and minus cylinder the visual acuity for these types of refractive error varied as would a straight spherical error which was the algebraic sum of the actual sphere and cylinder.

With less than three quarters of a diopter of hyperopia some individuals, while by refraction hyperopes, under low levels of illumination show a visual acuity characteristic of myopes and for practical purposes must be considered as such under actual operating conditions.

A few men were run through the test at levels up to 1000 foot candles but not enough of these tests have been done to do more than say that the results indicate a steady gain in visual acuity to a level of six foot candles, then a more rapid rise to 20 foot candles, thereafter a slow rise in all except myopes, and for all classes very little increase is shown above 100 foot candles.

The results indicate that a level of illumination and a level of visual acuity can be selected which will allow mass screening with a significant error in all probability of less than five percent.

Results with a small number of active pilots indicate that judgment of distance may become inaccurate at these low levels of illumination as a result of the development of a temporarily effective state of myopia with an accompanying change in image size.

The experimental work done has been of a practical nature merely accepting the eye as a working organ. There is however, evidence that the lowered visual acuity of low hyperopes is due to the development of sufficient spherical aberration on dilation of the pupil so that at low light levels the subject is no longer a hyperope but is a myope and that a basic non-cycloplegic hyperopia of at least three quarters of a diopter is necessary to prevent the development of such a condition of temporary myopia in a sufficient number of subjects to decrease the average visual acuity of the group.

A third and larger series of men is now being run, with geometrical rather than letter charts, at light levels of from 0.00027 foot candles to 1000 foot candles. The refraction of this group is being carried out in an examining room which was built to conform with the recommendations of the Army-Navy-OSRD Vision Committee.

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Preliminary studies on small numbers of subjects indicate that fatigue, nervous tension, anoxia of mild degree and the use of the eyes for near vision, each and all act to increase the tendency of hyperopes to behave as myopes under low illumination and may at times operate to a degree of very considerable significance in lowering visual acuity and increasing errors in distance judgment at a time when the accuracy of such observations may be of critical importance. It is planned to include some or all of these factors in the survey now being run.

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THE A. G. O. RESEARCH PROGRAM ON ACUITY TEST CHARTS

Calvin W. Taylor, Capt., AUS

A general plan for conducting various phases of research required in the visual examination project was developed by representatives of the Vision Committee in December and approved within the Personnel Research Section, A. G. O. The first phase of the project consists of a factor analysis study in which twelve proposed test charts will be administered under standard conditions in order to determine how many and what kinds of visual functions are measureable and the best tests for their measurement. In this phase, it is planned to test only far vision, no tests being included which require testing other than at a distance of twenty feet. The test charts include five types: Letter Charts, Brightness Contrast Charts, Simple Resolution Charts, Form Discrimination Charts, and Grid Discrimination Charts. Tests will be scored on the total number of items correct, preceding three consecutive errors. Various other kinds of scoring procedures will also be studied.

The experimental design calls for administration of the twelve selected charts to at least one thousand soldiers. The order of the charts will be held constant with the exception that each succeeding subject will begin one chart later in the series, this being done by inserting the chart that was previously first, into the last position before testing the next subject.

The first five hundred subjects will be retested on the entire series of the charts not less than eighteen nor more than seventy-two hours after initial testing. This will give sufficient data for investigating the reliability of each of the charts. On the first five hundred cases, factor analysis studies on both test and retest data will be performed and, on the second five hundred cases, a duplicate factor analysis will be undertaken to check the results on the first five hundred.

Allied data that will be collected on each subject tested include: age; AGCT Standard Score; number of school grades completed; previous visual examination records; whether or not the person wears glasses; day of the week, and hour of day of test; and whether results are for test or retest. Only the left eye will be tested during the entire experiment. Each response will be recorded as either right or wrong for all test charts, and the total test scores for each subject will be submitted to the Surgeon General and to The Air Surgeon.

It is realised that reliable data can be obtained only by having standardized testing procedures and conditions as well as standardized test items. Therefore, each visual test

included in the study will have standardized practice problems and directions, and all testing will be carried on in rooms meeting certain specified conditions. A manual now being prepared will include test directions, procedures and conditions, and will be based upon the "Manual of Instructions for Testing Visual Acuity" previously developed by members of this Committee. Each testing booth will be constructed and illuminated according to specifications in the Manual. A standard cloth is being used to form the walls, ceiling and floor of each test booth. Automatic chart changers are being constructed by Bausch & Lomb Optical Company and will be used for holding and presenting each successive chart.

There are several unsolved problems on which decisions must be reached before beginning the experimentation:

1. Is the list of test charts that have been selected for Phase I satisfactory and complete?

2. Is the scoring procedure satisfactory or what other kinds of scoring systems might be studied?

3. Is the practice problem satisfactory, for training subjects to guess?

4. In what manner should familiarization problems be presented for each chart, i.e. (a) should the familiarization chart be in the chart changer at twenty feet or (b) be held by the examiner at six feet away from the subject or (c) be given to the subject to read within his arm's length?

5. Should the cloth covering the floor be of the same color or a darker color than the cloth forming the remainder of the test booth?

6. What type of lighting (overhead or projected) should be used in each test booth, and what illumination readings should be required at what places in each test booth?

Discussion of the report was postponed until Wednesday afternoon when a special meeting of those interested in visual testing was called.

THE VISIBILITY PROGRAM OF THE NDRC

CAMOUFLAGE SECTION

Dr. Arthur C. Hardy
Formerly Chief, Section 16.3, NDRC

Dr. S. Q. Duntley
Technical Aide, Section 16.3, NDRC

Mr. H. Richard Blackwell
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NDRC, L. C. Tiffany Foundation
Oyster Bay, New York

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I. THE VISIBILITY PROGRAM OF THE N.D.R.C. CAMOUFLAGE SECTION
Dr. Arthur C. Hardy (presented by Dr. S. Q. Duntley).

Soon after the N.D.R.C. Camouflage Section was organized, the Corps of Engineers requested that a study be made of the fundamental optics of camouflage in the hope of establishing an engineering basis for the design of ground camouflage installations. In response to this request a contract was placed with the Eastman Kodak Company for the design and construction of an aerial spectrophotometer (later known as the "spectrogeograph"). While this and other needed instruments were being prepared, the Section was requested by the Navy Department to supply information concerning the visibility of naval targets. After a search of the literature had disclosed that usable data on the perceptual capacity of the human observer were not available, a large-scale program of visibility research was initiated by the Section. The following papers are intended to present a collation of the results of those researches by the Section and its contractors which now enable the visibility of targets to be predicted.

II. REDUCTION OF TARGET CONTRAST BY THE ATMOSPHERE
Dr. S. Q. Duntley.*

An important principle of atmospheric optics, which appears to have been missed by other investigators, states that the apparent contrast (C_x) of a distant target seen against a background of horizon sky is related to theinherent contrast (C_o) of the target when seen close aboard by the relation

$$C_x = C_o T^x,$$

where T is the transmittance of a unit distance (mile, yard, etc.) of the atmosphere, and X is the distance of the target from the observer. The validity of this equation was tested by measuring the apparent brightness of both black and white billboard-type targets erected by the Tiffany Foundation on the shores of Cold Spring Harbor, Long Island, N. Y. Both photoelectric and photographic telephotometers were used.

When a target is seen against a background whose brightness differs from that of the horizon sky, the apparent contrast of the target is related to its inherent contrast by the relation

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* A complete discussion of the topic will be found in the Summary Technical Report of N.D.R.C., Camouflage Volume.

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$$C_x = \frac{C_o}{1 + \frac{B_H}{B_o}\left(T^{-x} - 1\right)},$$

where B_H is the brightness of the horizon sky in the direction of the target, and B_o is the brightness of the background.

From laboratory studies on visibility point sources were found to be visible day or night whenever they produce a certain minimum value of illumination on the pupil of the observer's eye, the required value of illumination depending upon the brightness of the background against which the point source is viewed. The illumination (E) is related to the intensity of the source (I), its distance, and the transmittance of the atmosphere by the relation

$$E = \frac{I}{x^2} T^x.$$

A nomographic chart representing this relation is shown in Figure 1. Each curved line corresponds to a decimal value of adaptation brightness expressed in footlamberts. Place a straightedge across the chart in such a manner that it connects the appropriate value on themeteorological range scale with a point on the intensity scale corresponding to the candlepower of the signal light. Where the straightedge is intersected by the appropriate curved line, move straight up or straight down to the scale of target distance. The value read on this scale will be the distance at which the signal light is liminally visible.

III. LABORATORY STUDIES OF THE VISIBILITY OF TARGETS
H. Richard Blackwell

A. Introduction.

As a portion of the program of the Camouflage Section of NDRC, experiments were conducted at the Tiffany Foundation, Oyster Bay, New York, to establish the human capacity for visual detection. The experiments were designed to simulate field conditions with provision for precise control over the variables known to be relevant. It was desired that visual functions be quantified so that the capacity of the human observer could be treated as one of the known variables contributing to the visibility of targets.

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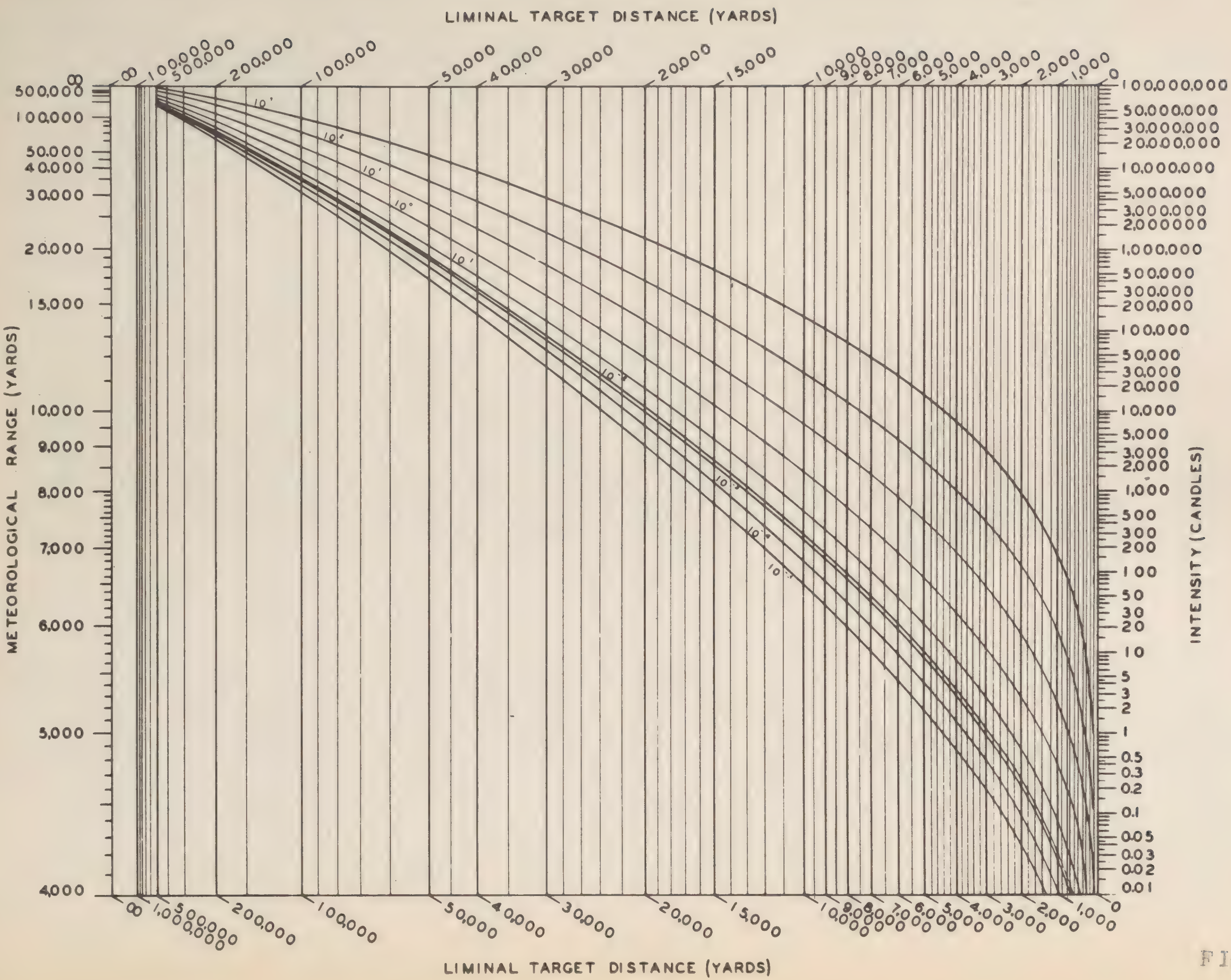

LIMINAL TARGET DISTANCE (YARDS)
METEOROLOGICAL RANGE (YARDS)
INTENSITY (CANDLES)
LIMINAL TARGET DISTANCE (YARDS)

FIG 1

[redacted]

Exact data were required for a wide range of experimental conditions. Sky brightnesses vary 10 billion to 1 under ordinary conditions. Targets vary in size from signal lights to land masses. Equivalent variations are encountered in target contrast and shape and in the time during which an object is in the visual field.

Provisions were made, accordingly, for the accumulation of large numbers of data. During two and one-half years, more than 2,000,000 observations of targets were made under laboratory conditions.

B. General Experimental Conditions.

A laboratory was constructed at Tiffany, designed especially to permit the rapid accumulation of experimental data. A plywood structure was installed within an existing framework. The main portion of the plywood structure was the illuminated room in which observations were made. Observers were stationed at the rear of the room who scanned the opposite wall, 61 feet distant, on which the targets were always produced. Equipment for controlling the brightness of the observation room and for producing the targets was contained in the control room at the rear.

In order to facilitate rapid accumulation of data, simultaneous observations of each target presentation were made by nine observers. An experimental session consisted of 320 target presentations, in which screen brightness and target size were maintained constant. The experimental variable was the contrast between the target and the surrounding field. Five fixed contrast values were presented in random sequence and the observers were required in each case to attempt to detect the target. The probability of their success in detection was a function of the contrast of the target. A graph of probability of detection and contrast is shown in Figure 1. Typical data are fitted by a curve which is simply the integral of the Gaussian distribution. Reading from the curve, we see that a change in contrast of 4 to 1 corresponds to a change in probability of detection from 98% to 2%.

A special recording system was developed in order to obtain the data necessary for construction of probability curves for each of the observers. For most experiments, targets of circular shape were projected onto the observation screen from the main control room. Interlocking electrical controls were developed so that the characteristics of the target, such as its brightness and its location on the screen, were indicated at the master recording panels at all times.

The observers were seated in upholstered theatre chairs, on the arms of which were mounted dials used in indicating

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their judgment concerning the target. The dials were appropriately wired so that continuous records of the judgments of each of the observers were available on the master recording panels.

The recording system made possible, therefore, immediate composite records of all pertinent information concerning an experimental trial, including the brightness and location of the target and the judgments of each of the observers. Permanent records were made from the master panels for each of the 200,000 experimental trials conducted.

Each experimental session consisted, therefore, of 3,000 observations in which the probability of detection of a target of given size was determined as a function of its contrast, with a specified screen brightness. Data are available for each observer in the form of a probability curve. The threshold contrast for each observer is defined as the contrast corresponding to a probability of detection 50% greater than attributable to chance. This procedure was selected because the probability curve is most sensitive at the 50% point.

Because of the finite number of possible responses in a laboratory experiment, there is always a calculable probability of detection resulting from chance alone. For example, if observers were asked to ascertain whether a target was in the top or bottom portion of a screen, they would make 50% correct judgments on the basis of chance. The actual probability of detection due to visual cues could be computed by allowing for chance successes. In this case, the probability 50% better than chance would correspond to 75% correct judgments. Henceforth in this discussion, probability curves will have been corrected to account for chance success.

The Arithmetical Mean of the threshold contrasts of each of the observers is taken as the most reliable measure of the threshold of the group. The group threshold contrast is, obviously, above threshold for some observers and below threshold for others. Figure 2 illustrates this fact. The probability curve for the group is plotted as the central curve. The group threshold contrast of 1.0 corresponds to a probability of detection for the group of 50%. The curves bracketing the group probability function represent the least and most sensitive observers in the group. This is a record of an actual experiment, typical of the kind of differences which exist in a group of selected observers. It is apparent that the group threshold contrast can be detected by the worst observer with a probability of only 20% and by the best observer with a probability of 70%.

Interrogation revealed that observers have no confidence in their judgments unless the contrast is great enough so that

they are making 90% correct judgments. It is very striking that observers can be responding correctly on 75% of target presentations without feeling confident that they have "seen" a single target. This fact emphasizes that the Tiffany threshold contrasts are substantially smaller than would have resulted with the same observers under field conditions.

From this analysis, we may conclude that usually none of the observers had any confidence of success when the target contrast was equal to the group threshold contrast. They were trained in the laboratory to record their hunches and of these, a large percentage proved to be correct.

As we have seen, the selection of our threshold criterion was at least partially the result of precision considerations. Fortunately, a simple correction can be applied if a different criterion is desired. Insofar as the slopes of the probability curves are the same for all experiments, conversion can be made from one probability level to another by a simple manipulation of contrast. Elaborate statistical treatment has been made of more than 1,500 individual probability curves to determine the constancy of their slopes. The slopes of the individual probability functions usually fell within the limits of the dark area shown in Figure 3. The extreme range of slopes is indicated by the dashed curves. It is apparent that the error introduced by assuming a constant slope for the probability function is not of military significance. In order for threshold contrasts to be seen with certainty on the average by the group of observers, a factor of two must be applied.

Preliminary experiments at the Tiffany Foundation indicated that visual functions are extremely well defined if large numbers of observations are made under controlled conditions. It became evident that the precision of ordinary photometric measurements was less than the precision of the visual observations. For this reason, elaborate photometric techniques were used in the final Tiffany experiments.

Photometric quantities were defined in terms of a 2850°K standard by photopic evaluation. Special laboratory techniques were devised which made it possible for surface brightnesses as small as 1×10^{-6} footlamberts to be evaluated at brightness levels not less than 1×10^{-1} footlamberts. At least two independent measurements were made of each surface brightness.

C. Experimental Results. Program I

The first extensive program conducted included more than 250,000 observations. A circular target was projected onto the observation screen in one of eight possible locations. A small orientation point was provided the observers at the center of the circle on whose circumference the targets were

located. The observers were given a six-second period in which to locate the target and to report its position. The results are presented in Figure 4. The logarithm of the group threshold contrast is presented as a function of the logarithm of the brightness of the observation screen for each of five target sizes. These curves show two interesting facts about visual capacity: At high brightnesses, and especially for large targets, contrast becomes a constant value with respect to brightness level. For a 2^{o} target, for example, there is no substantial difference in the threshold contrasts for field brightnesses varying from 100 to 1 footlamberts. It can be assumed that extrapolation to higher brightnesses is permissible.

Each of the curves shows a discontinuity at approximately 5×10^{-3} footlamberts. It is assumed that the two types of sensory receptors in the eye are responsible for the two portions of the curves. Since the observers were allowed to search for the targets as they chose, it would be expected that a discontinuity would occur when they changed from foveal to parafoveal vision. Interpolations are presented in Figure 5. The logarithm of the group threshold contrast is plotted against the logarithm of the angle subtended by the target. Curves are presented for brightness levels ranging from the darkest night to a moderate day-time level. Extrapolation to higher brightnesses would be permissible because contrast is so nearly constant for change in brightness. A further manipulation of the data is presented in Figure 6. Target area is plotted against the total physical energy required for threshold detection. It is interesting to notice that there is little difference in the threshold total flux for brightnesses varying from 1×10^{-5} footlamberts to total darkness.

Program II

More than 125,000 observations were made to determine whether circular targets darker than their background have visibility equivalent to circular targets brighter than their background of corresponding contrast. The procedures were substantially the same as those previously described. The results are shown in Figure 7. The solid curves represent data for bright targets and the points represent experimental values for dark targets of the same size. It can be concluded that over the range at which dark targets exist, their visibility is not significantly different from that of corresponding bright targets.

Program III

In the experiments previously described, a relatively short time was available for the observers to search for the target. The experimental conditions were considered similar to many of the most pertinent military situations. There are, however, military situations in which there is almost unlimited

time to search. Accordingly, 90,000 observations were made in which the observers had sufficient time to permit maximum probability of detection. The circular targets were presented in a fixed position, known to the observers. The observers were required to judge whether or not they detected the presence of the target. Presentations were interspersed in which a target was not shown to permit proper solution of the probability of detection curves.

Analysis of the earlier experimental programs indicated the need for targets larger than 2° and smaller than 3 minutes. On the other hand, analysis indicated that there was no necessity for investigating further screen brightnesses smaller than 1×10^{-5} footlamberts. Further, the large number of observations made previously to determine the nature of the discontinuity in the visual functions made it unnecessary for similar investigations to be made in this supplementary program. The results of the study are presented in Figure 8. Interpolations are shown in Figure 9.

Each curve exhibits a linear portion for small visual angles, corresponding to the fact that the product of area and target brightness is a constant. For the linear portion of each curve, targets are effectively "point sources", that is, the same visual effect is obtained by doubling the area or by doubling the brightness. The point at which each curve departs from linear corresponds to a fundamental property of the human eye. "Critical visual angle" is defined as the angle at which the relationship of area x brightness = a constant ceases to exist. "Critical angle" is plotted as a function of field brightness in Figure 10. It is apparent that this curve is similar in shape to the curves relating threshold contrast to field brightness.

Interpolations, indicating the relation between field brightness and visual angle for various values of contrast are exhibited in Figure 11. These curves show discontinuities which indicate the change between foveal and parafoveal vision. For high contrasts the curves are parallel, indicating that area x brightness = a constant.

It is interesting to consider that the smaller a target, the more efficient is the use of physical energy. This is shown by plotting the inverse of total flux, as in Figure 12. Maximum efficiency is obtained for increasingly large targets at increasingly small field of brightnesses. This corresponds to the fact that larger targets are below the "critical angle" for smaller field brightnesses.

Program IV

A program was undertaken to determine the effect of shape upon the visibility of targets. Experiments were designed

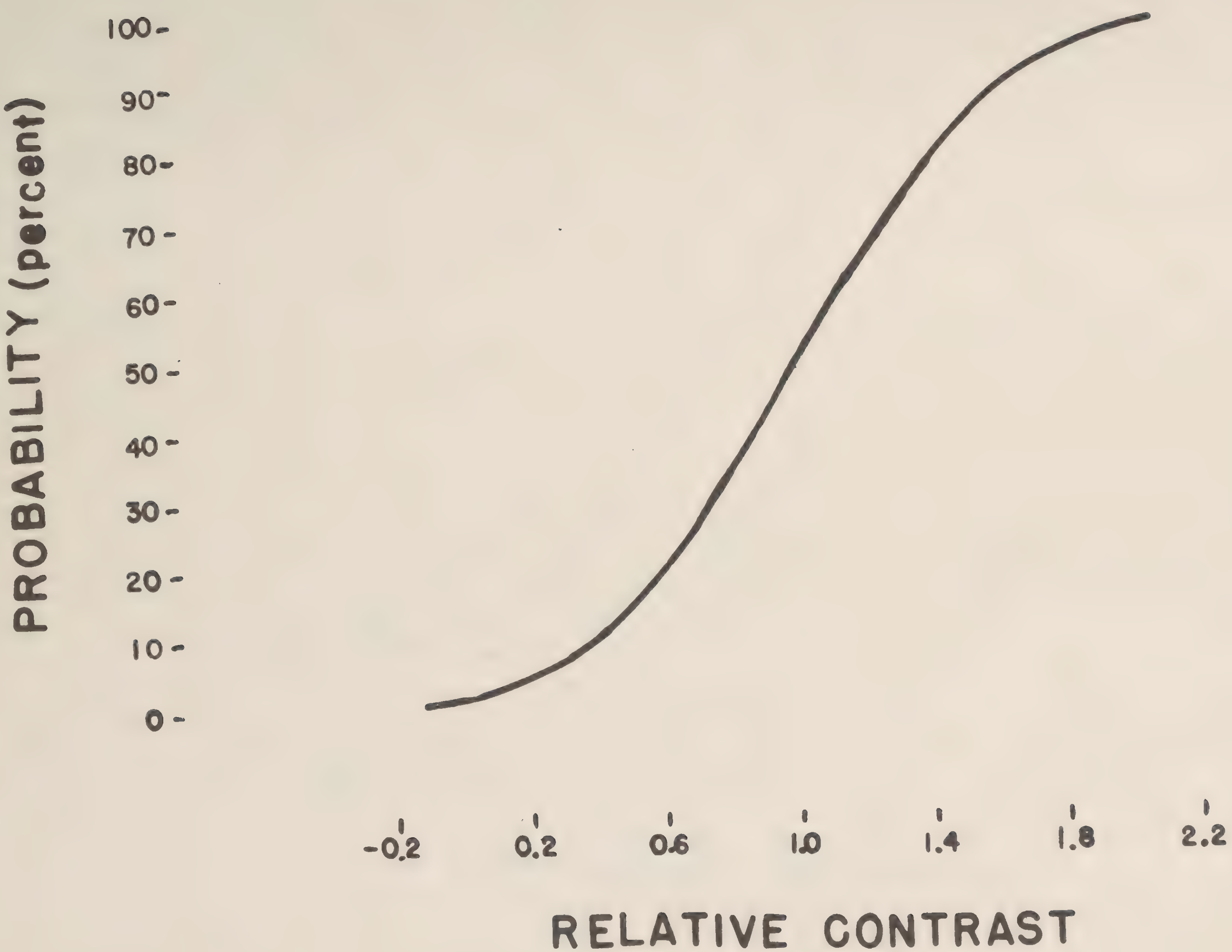
specifically to test the plausibility of the following theoretical treatment proposed by Professor Hardy: If a target is small enough so that it is below the limit of resolution of the eye, its shape has no influence upon its visibility. Under these conditions, minimum physical energy is required. In other words, maximum efficiency is obtained. If one dimension of such a "point source" target is maintained below the limit of resolution, and the other expanded, a loss in efficiency will be obtained. Presumably, similar data will be obtained if the opposite dimension is expanded. The efficiency of a square target, one which expands in both dimensions, is the product of the efficiency of the horizontal and vertical components. Conversely, by taking the square root of efficiency for square targets, efficiency for a "point source" target expanded in one dimension can be obtained.

This treatment makes it possible for the visibility of targets of irregular shape to be computed from visibility data obtained with square targets. Experimental evidence reveals that square and circular targets of equal area have equal visibility. It is, therefore, possible to evaluate the visibility of targets of irregular shape from the experimental data described previously. Efficiency functions are produced for "point source" targets expanded in one dimension. The efficiency of an irregularly shaped target is computed from the efficiency of its horizontal and vertical components. These data can be transformed into contrast units.

Theoretical predictions of the visibility of irregular targets are presented in Figure 13. The concept "form factor" is defined as the threshold contrast of an irregular target divided by the threshold contrast of a circular target of corresponding area. It is apparent that the magnitude of the "form factor" attains a maximum at increasingly large targets for increasingly small field brightnesses.

Experiments were conducted to verify the theoretical predictions. Critical points at 10 and at 1×10^{-5} footlamberts were investigated. Agreement was obtained within the experimental error of observations.

It is apperent that the experiments reported cover a wide range of experimental conditions. Field brightnesses have been investigated ranging from 100 footlamberts to total darkness. Target sizes have been studied ranging from 360 to 0.6 minutes of arc. Shapes have been investigated from circles to 100:1 rectangles. Exposures have been tested from six-seconds to indefinitely long time. Studies have been made of targets both brighter and darker than the background.



PROBABILITY (percent)
100
90
80
70
60
50
40
30
20
10
0
-0.2
0.2
0.6
1.0
1.4
1.8
2.2
RELATIVE CONTRAST

FIG 1

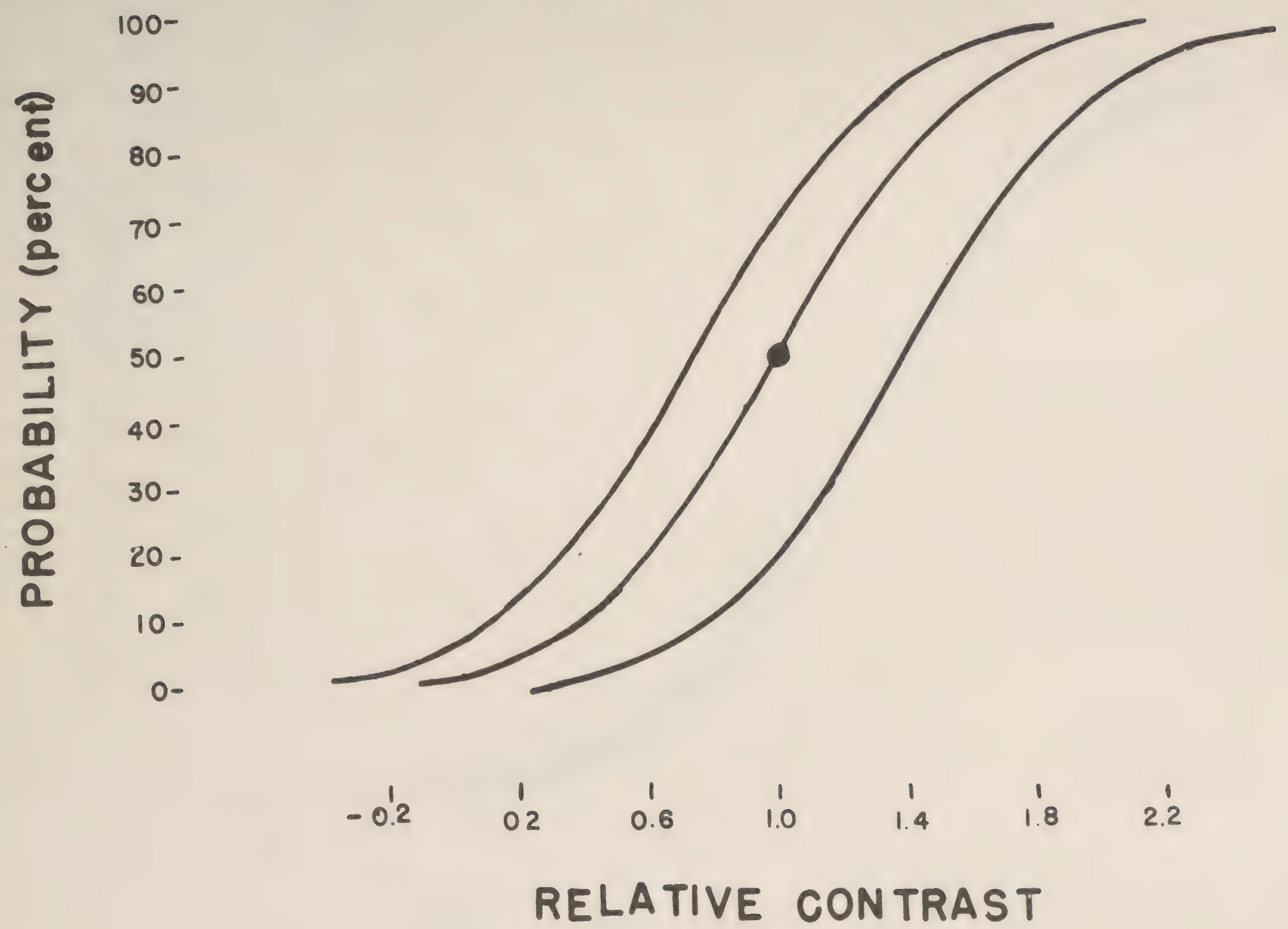
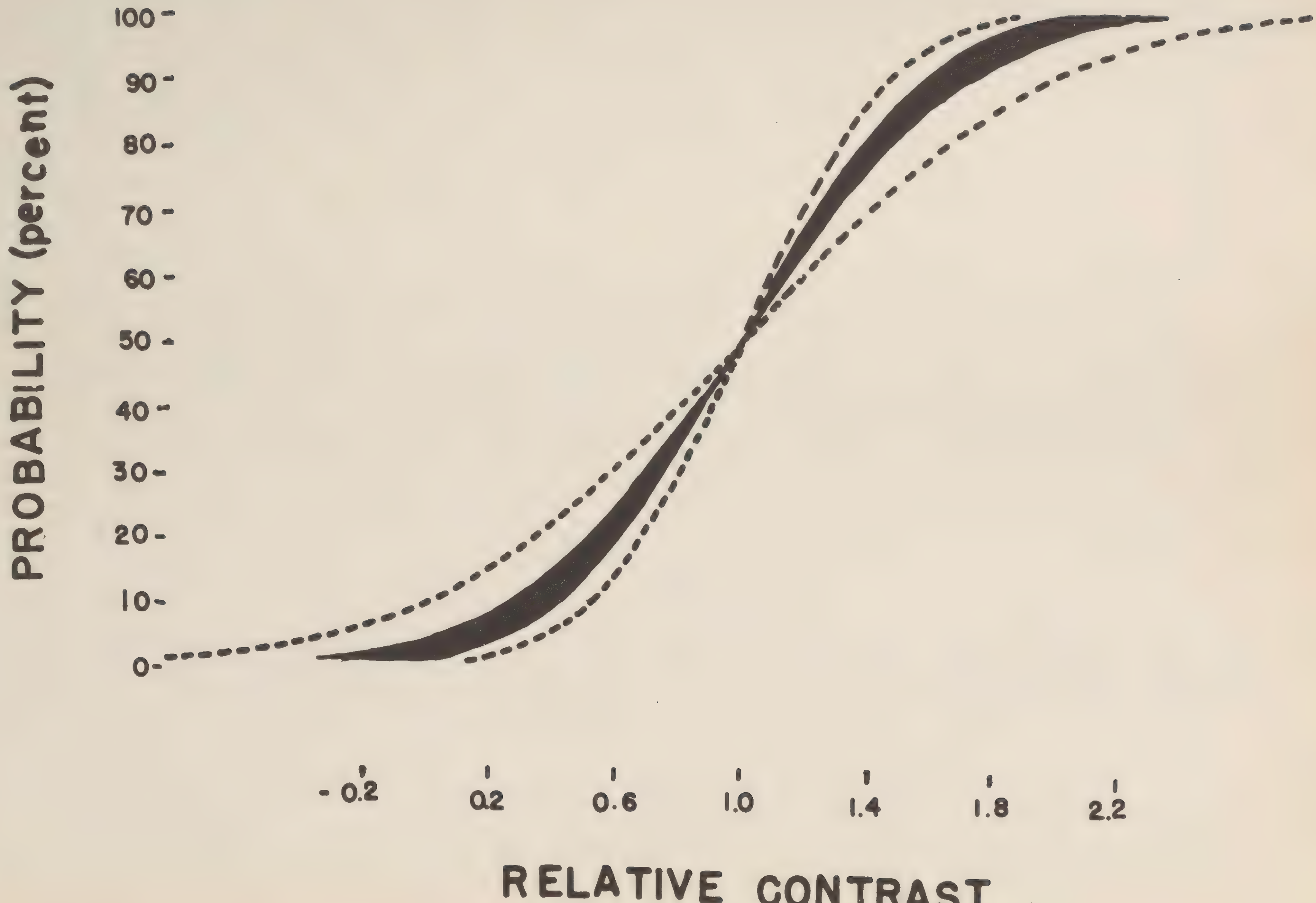

PROBABILITY (percent)
100
90
80
70
60
50
40
30
20
10
0
-0.2
0.2
0.6
1.0
1.4
1.8
2.2
RELATIVE CONTRAST

FIG 2



PROBABILITY (percent)
100
90
80
70
60
50
40
30
20
10
0
- 0.2
0.2
0.6
1.0
1.4
1.8
2.2
RELATIVE CONTRAST

FIG 3

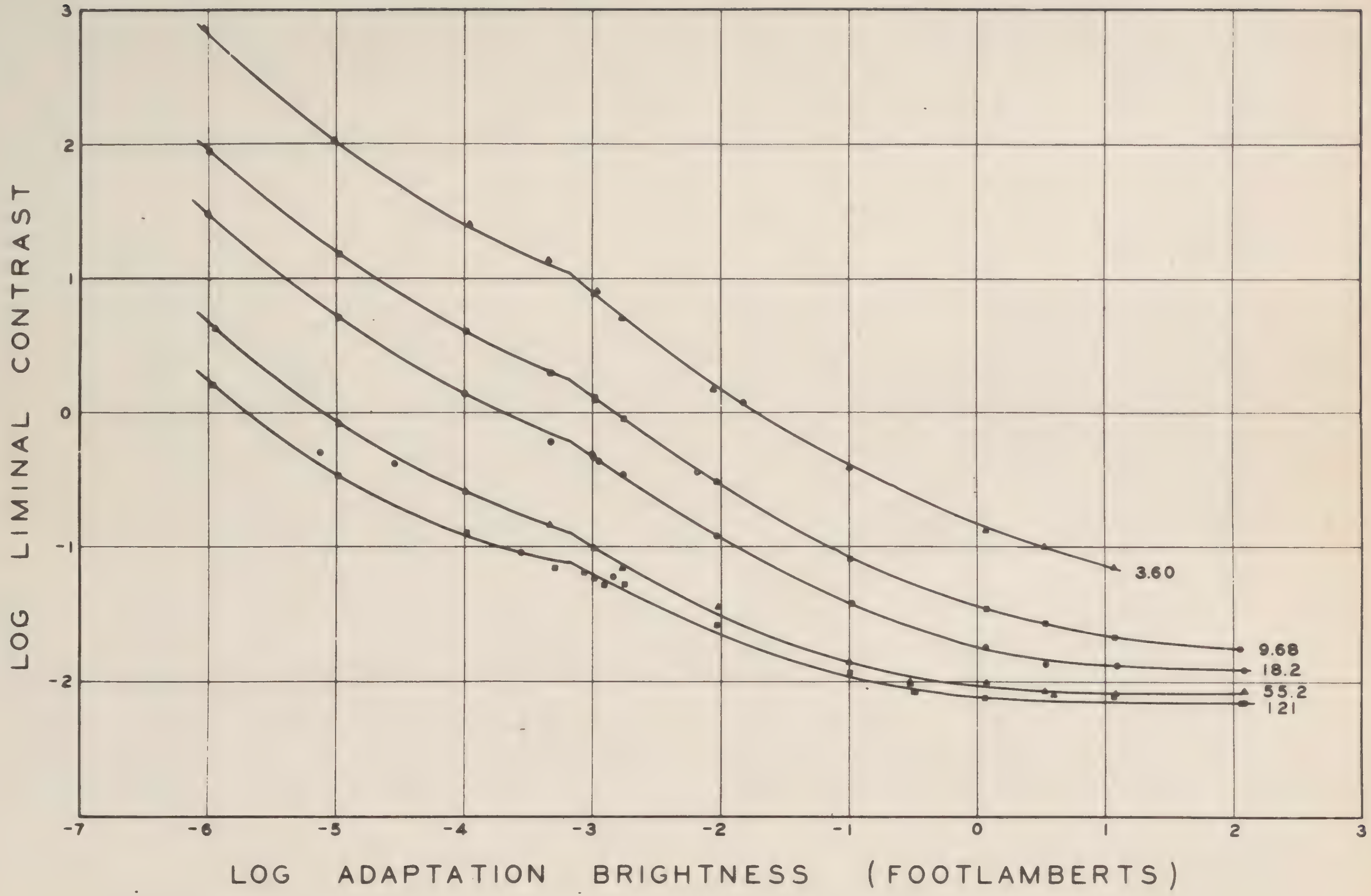

3
2
1
0
-1
-2
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
3.60
9.68
18.2
55.2
121
LOG LIMINAL CONTRAST
LOG ADAPTATION BRIGHTNESS (FOOTLAMBERTS)

FIG 4

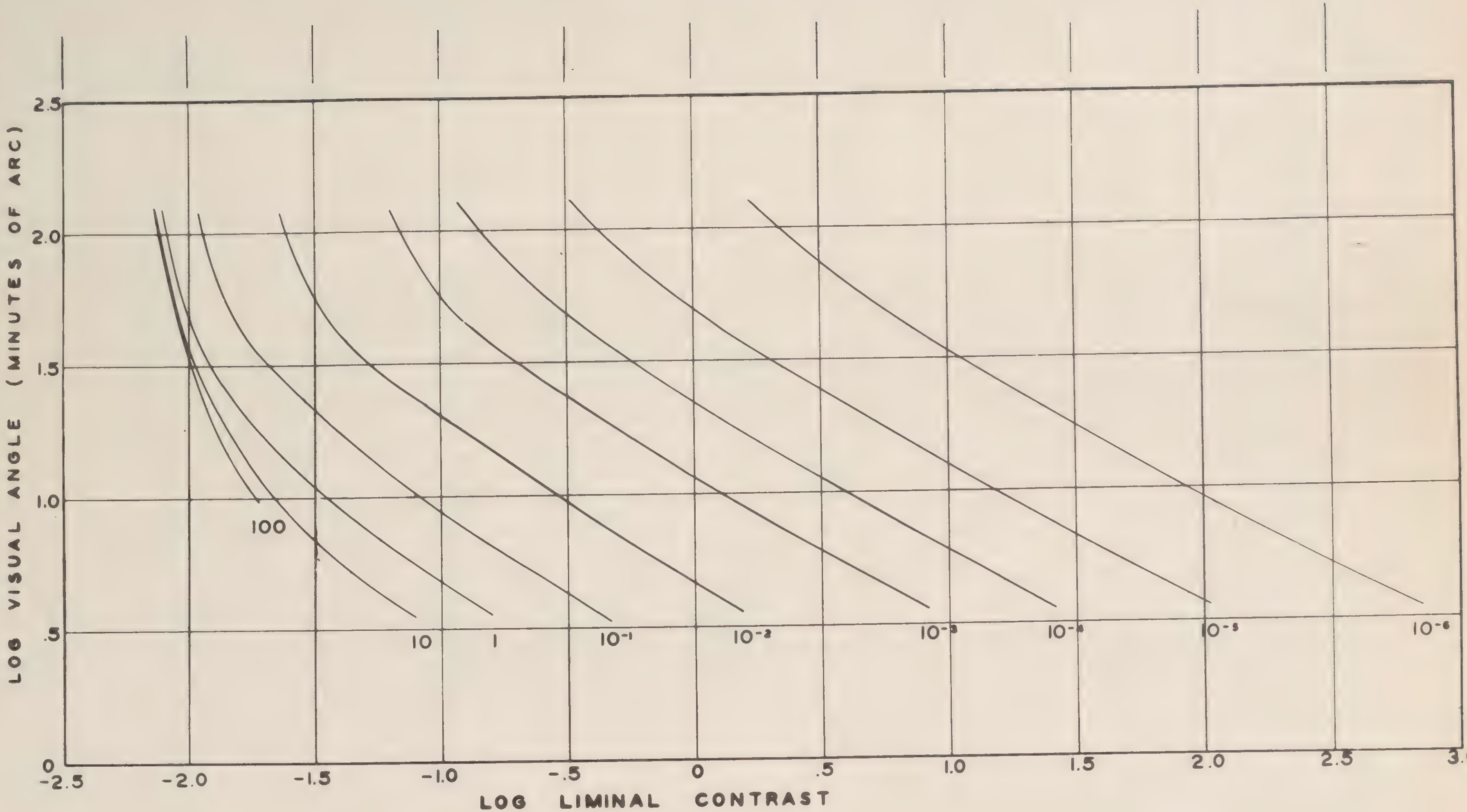

LOG VISUAL ANGLE (MINUTES OF ARC)
2.5
2.0
1.5
1.0
.5
0
-2.5
-2.0
-1.5
-1.0
-.5
0
.5
1.0
1.5
2.0
2.5
3.0
LOG LIMINAL CONTRAST
100
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶

FIG 5

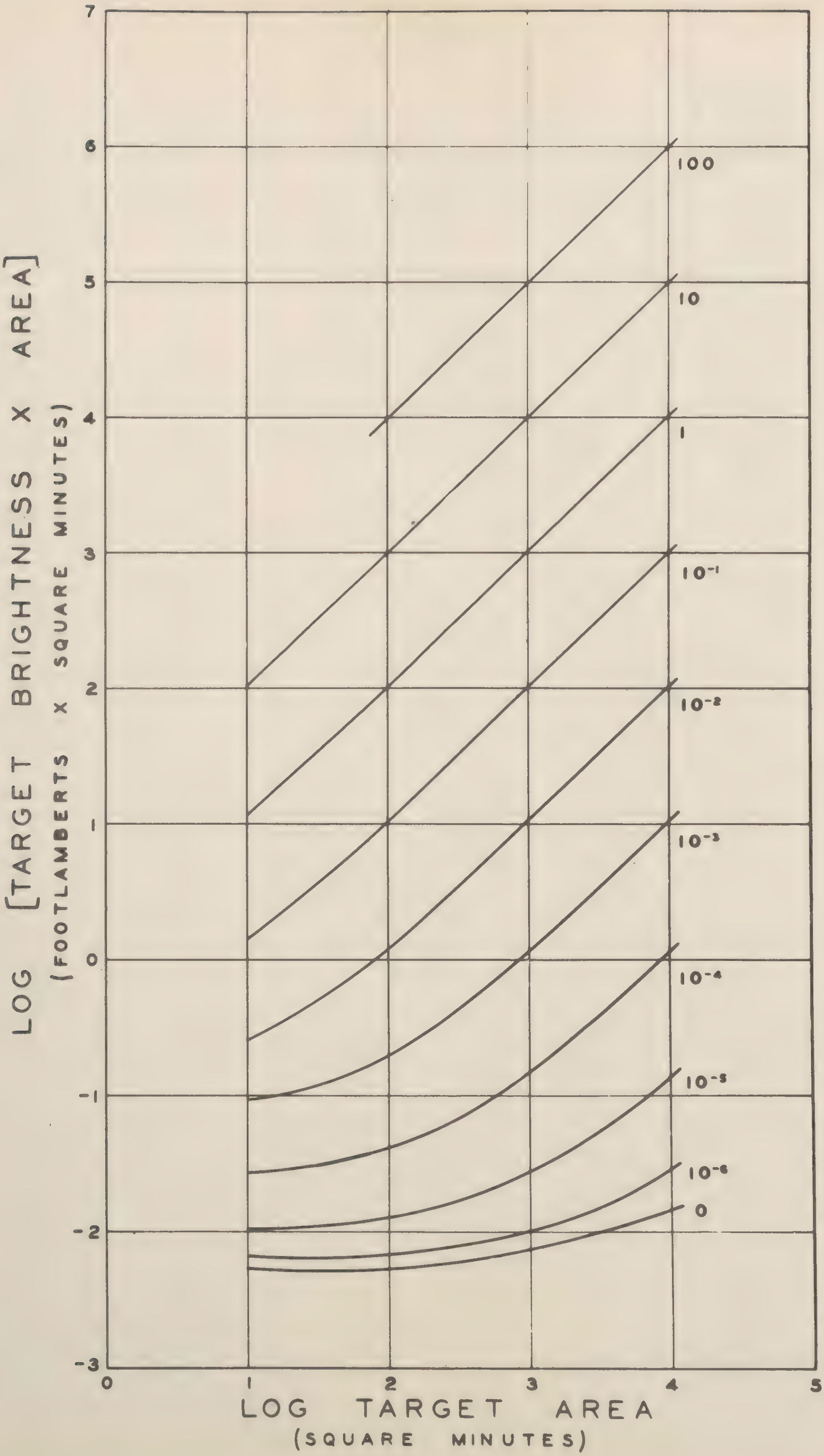

LOG [TARGET BRIGHTNESS X AREA]
(FOOTLAMBERTS X SQUARE MINUTES)
7
6
5
4
3
2
1
0
-1
-2
-3
0
1
2
3
4
5
100
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
LOG TARGET AREA
(SQUARE MINUTES)

FIG 6

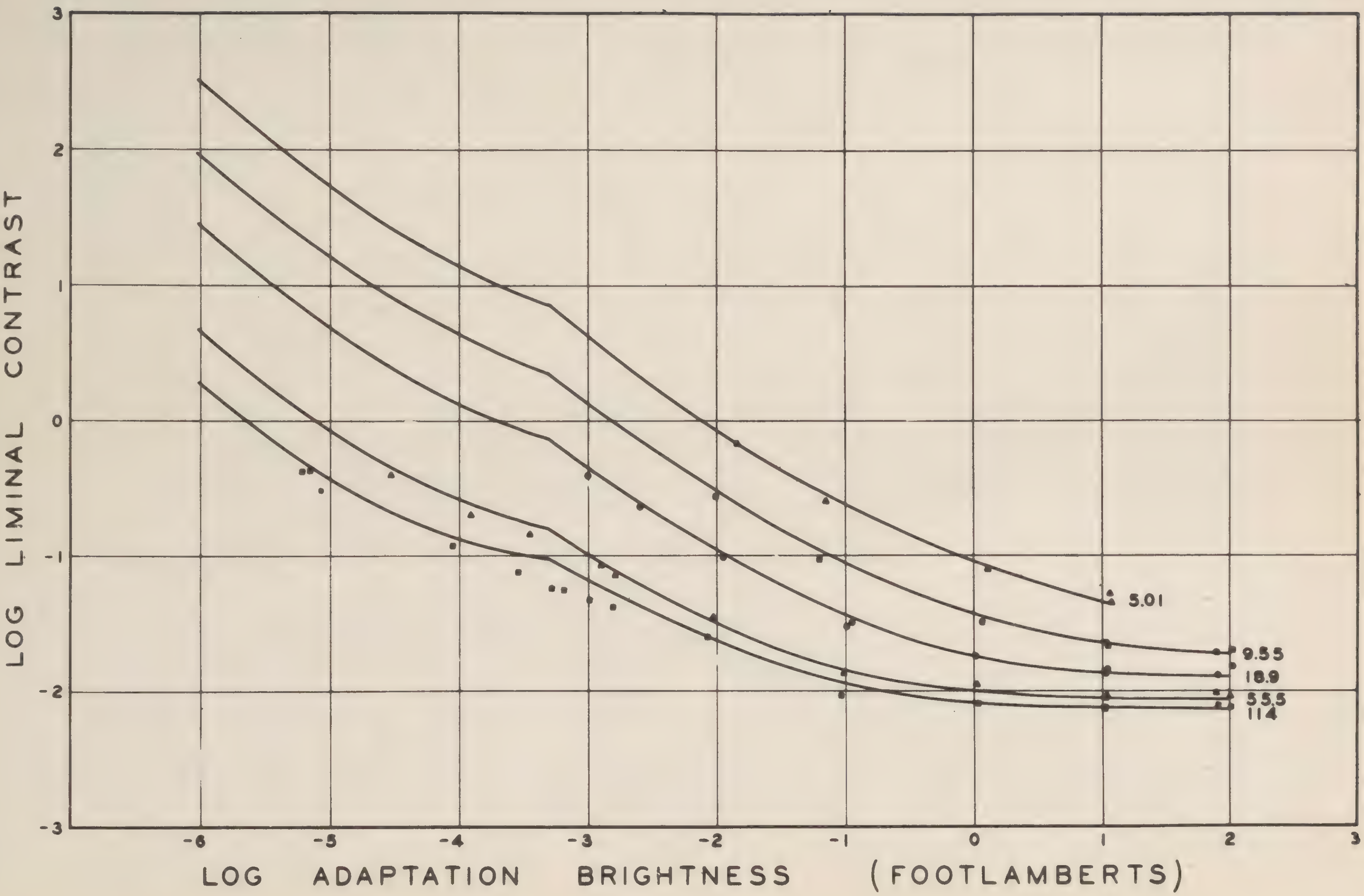

3
2
1
0
-1
-2
-3
LOG LIMINAL CONTRAST
-6
-5
-4
-3
-2
-1
0
1
2
3
LOG ADAPTATION BRIGHTNESS (FOOTLAMBERTS)
5.01
9.55
18.9
55.5
114

FIG 7

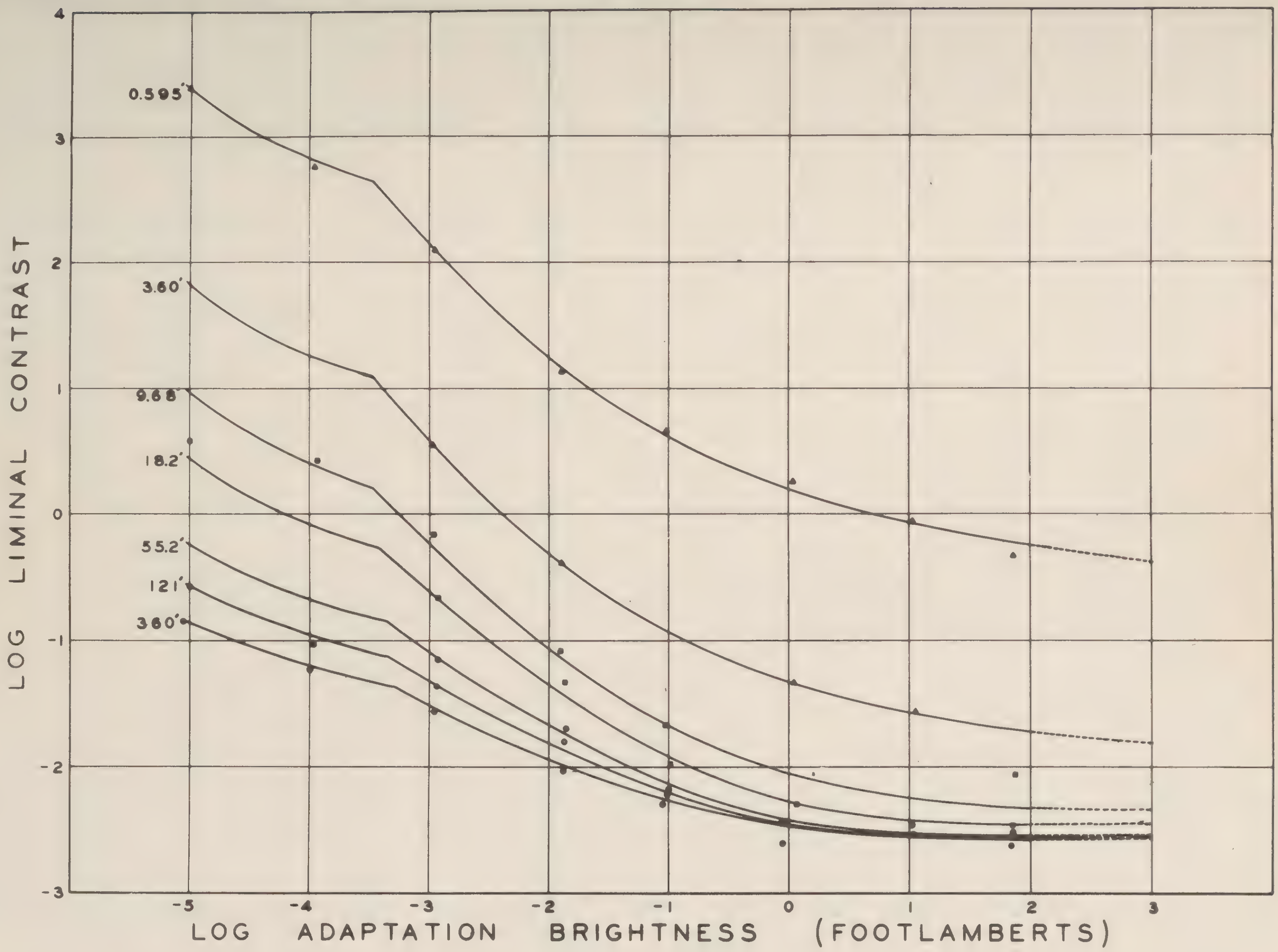

0.595'
3.60'
9.68'
18.2'
55.2'
121'
360'
4
3
2
1
0
-1
-2
-3
LOG LIMINAL CONTRAST
-5
-4
-3
-2
-1
0
1
2
3
LOG ADAPTATION BRIGHTNESS (FOOTLAMBERTS)

FIG 8

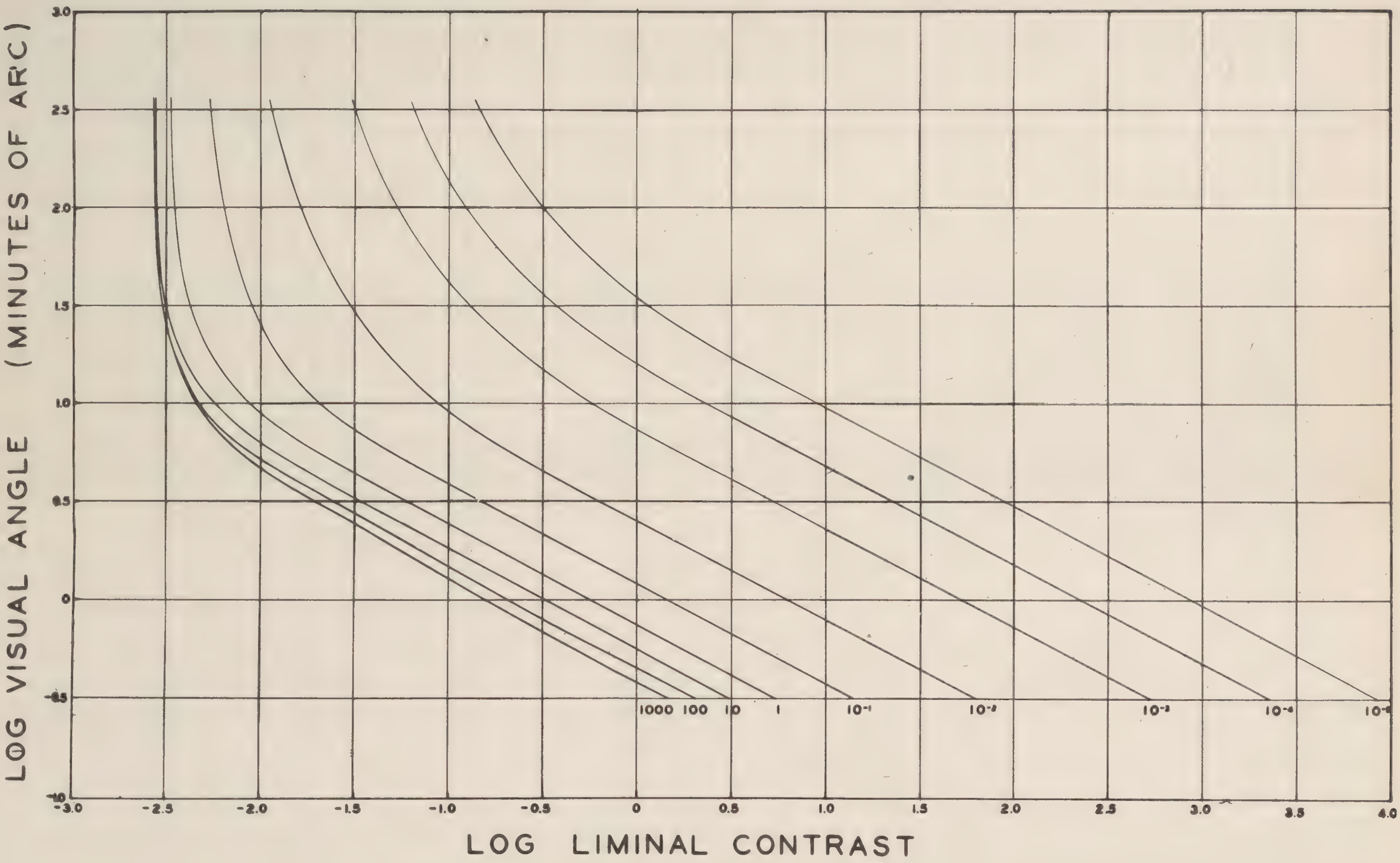

LOG VISUAL ANGLE (MINUTES OF ARC)
LOG LIMINAL CONTRAST
1000 100 10 1 10⁻¹ 10⁻² 10⁻³ 10⁻⁴ 10⁻⁵

FIG 9

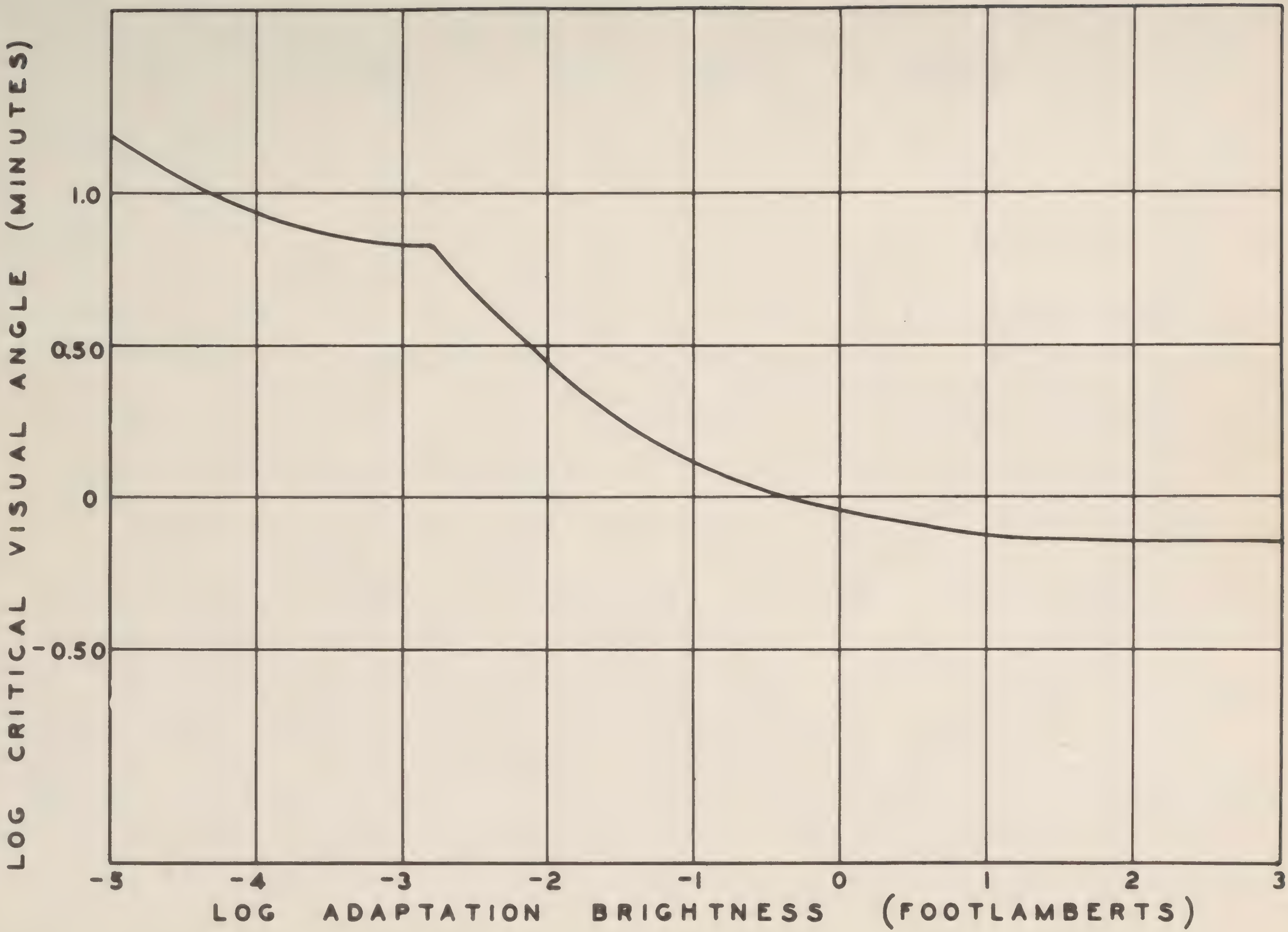
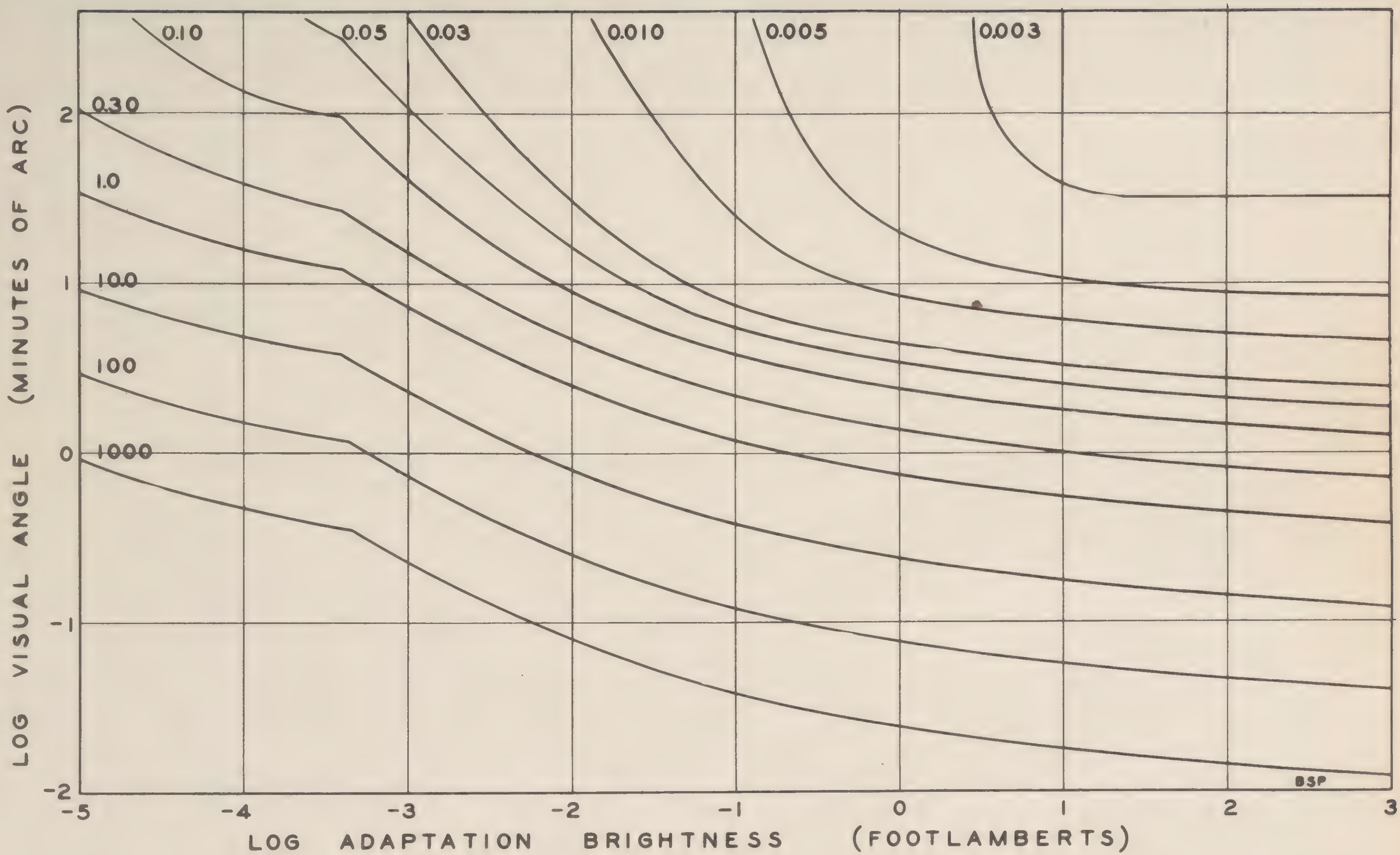

LOG CRITICAL VISUAL ANGLE (MINUTES)
1.0
0.50
0
-0.50
-5
-4
-3
-2
-1
0
1
2
3
LOG ADAPTATION BRIGHTNESS (FOOTLAMBERTS)

FIG 10



0.10
0.05
0.03
0.010
0.005
0.003
0.30
1.0
10.0
100
1000
2
1
0
-1
-2
-5
-4
-3
-2
-1
0
1
2
3
LOG VISUAL ANGLE (MINUTES OF ARC)
LOG ADAPTATION BRIGHTNESS (FOOTLAMBERTS)
BSP

FIG 11

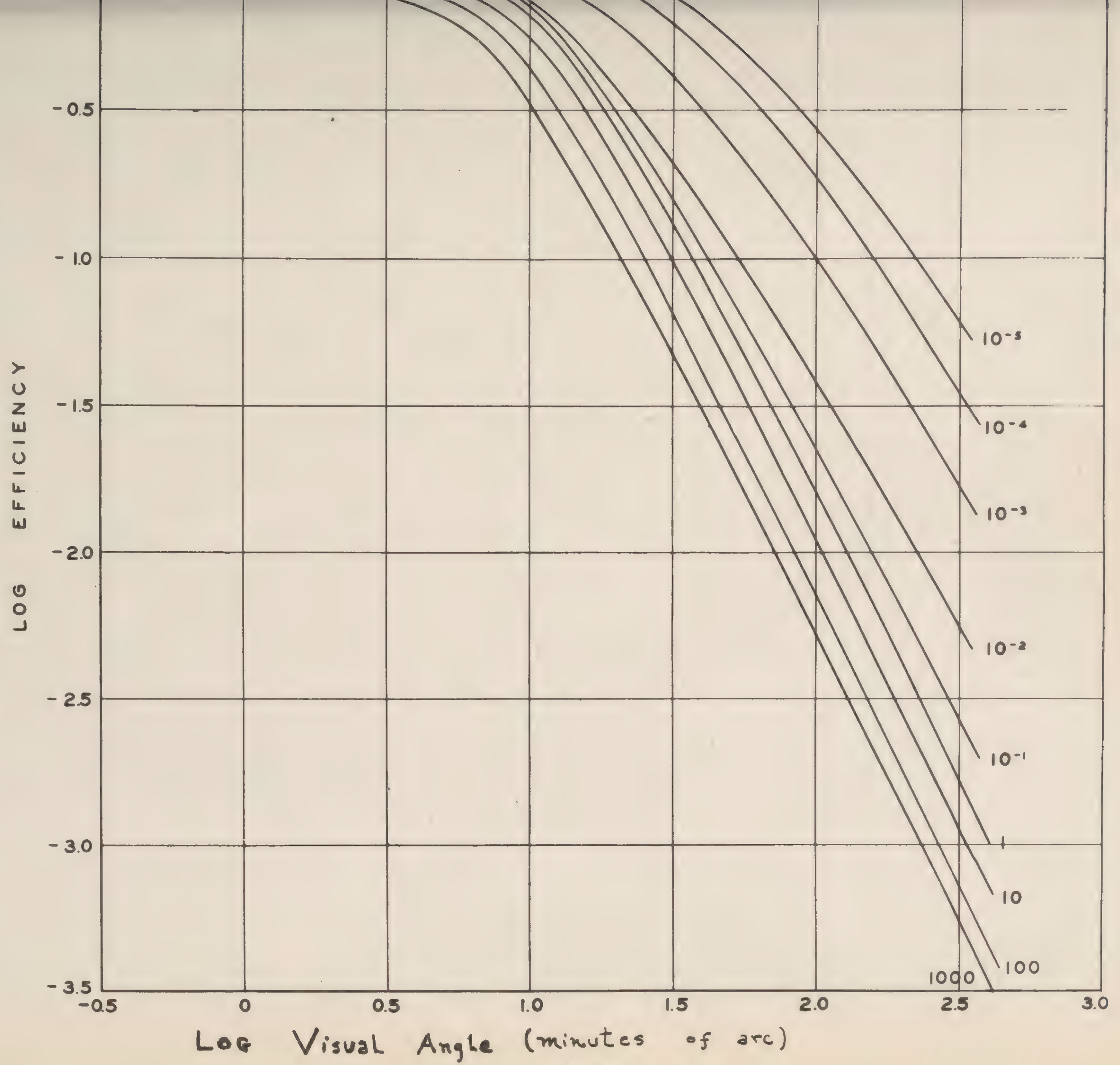
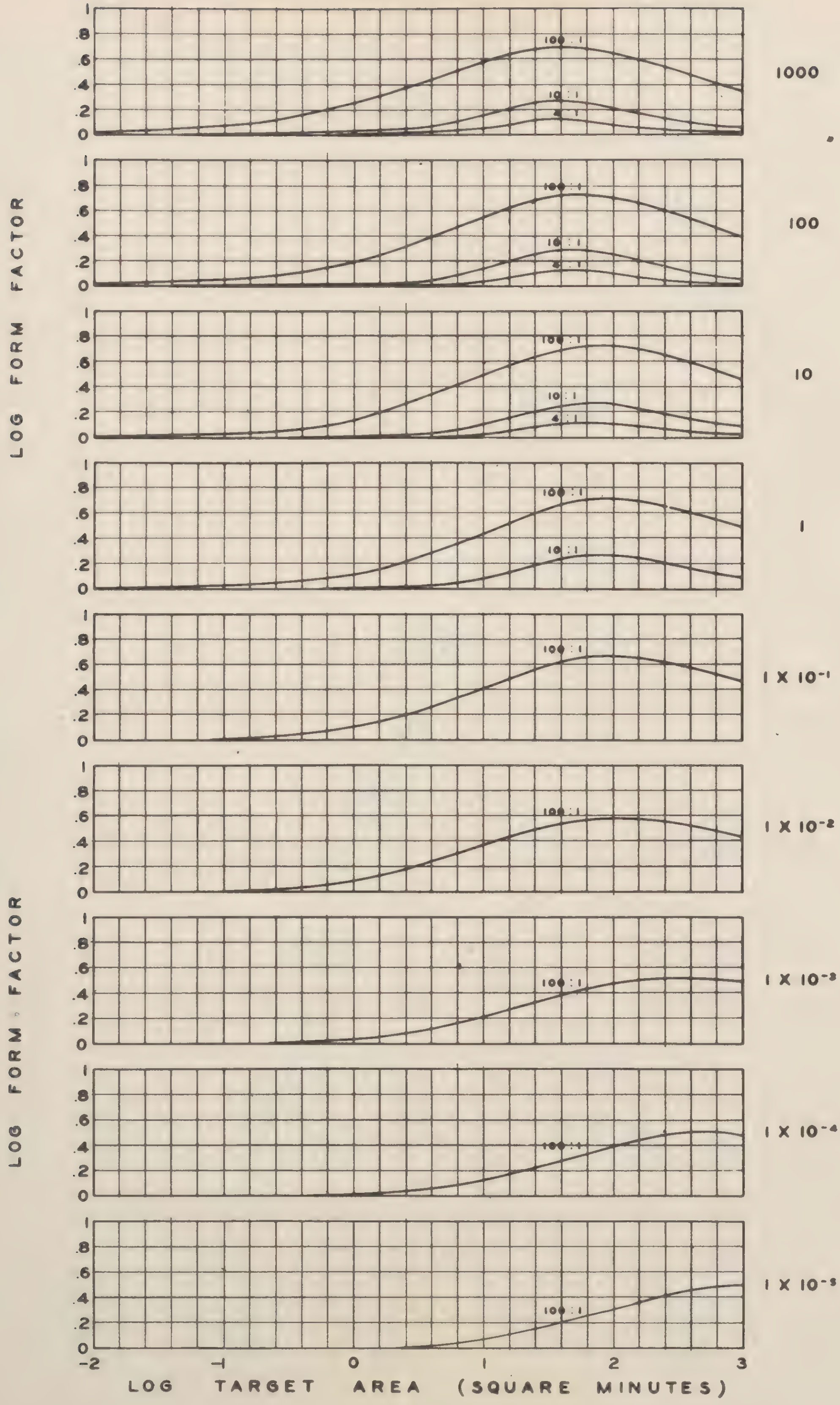

LOG EFFICIENCY
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-0.5
0
0.5
1.0
1.5
2.0
2.5
3.0
Log Visual Angle (minutes of arc)
10⁻⁵
10⁻⁴
10⁻³
10⁻²
10⁻¹
1
10
100
1000

FIG 11

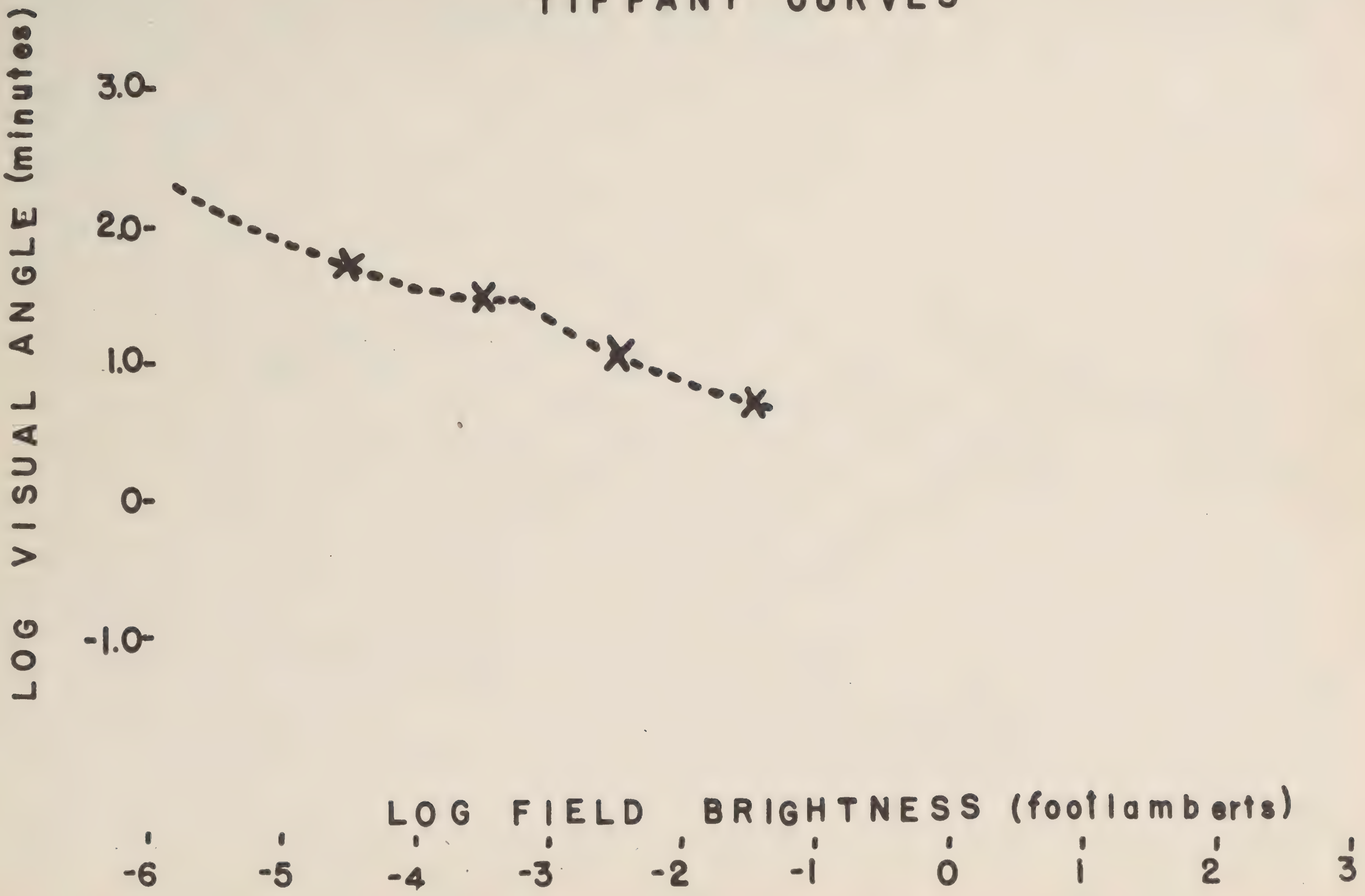


LOG FORM FACTOR
LOG FORM FACTOR
LOG TARGET AREA (SQUARE MINUTES)
1000
100
10
1
1 X 10⁻¹
1 X 10⁻²
1 X 10⁻³
1 X 10⁻⁴
1 X 10⁻⁵
100 : 1
10 : 1
4 : 1

FIG 13

DARTMOUTH DATA

FITTED BY CORRESPONDING TIFFANY CURVES



ROCHESTER DATA:

FITTED BY TIFFANY CONTRASTS

X 1.44

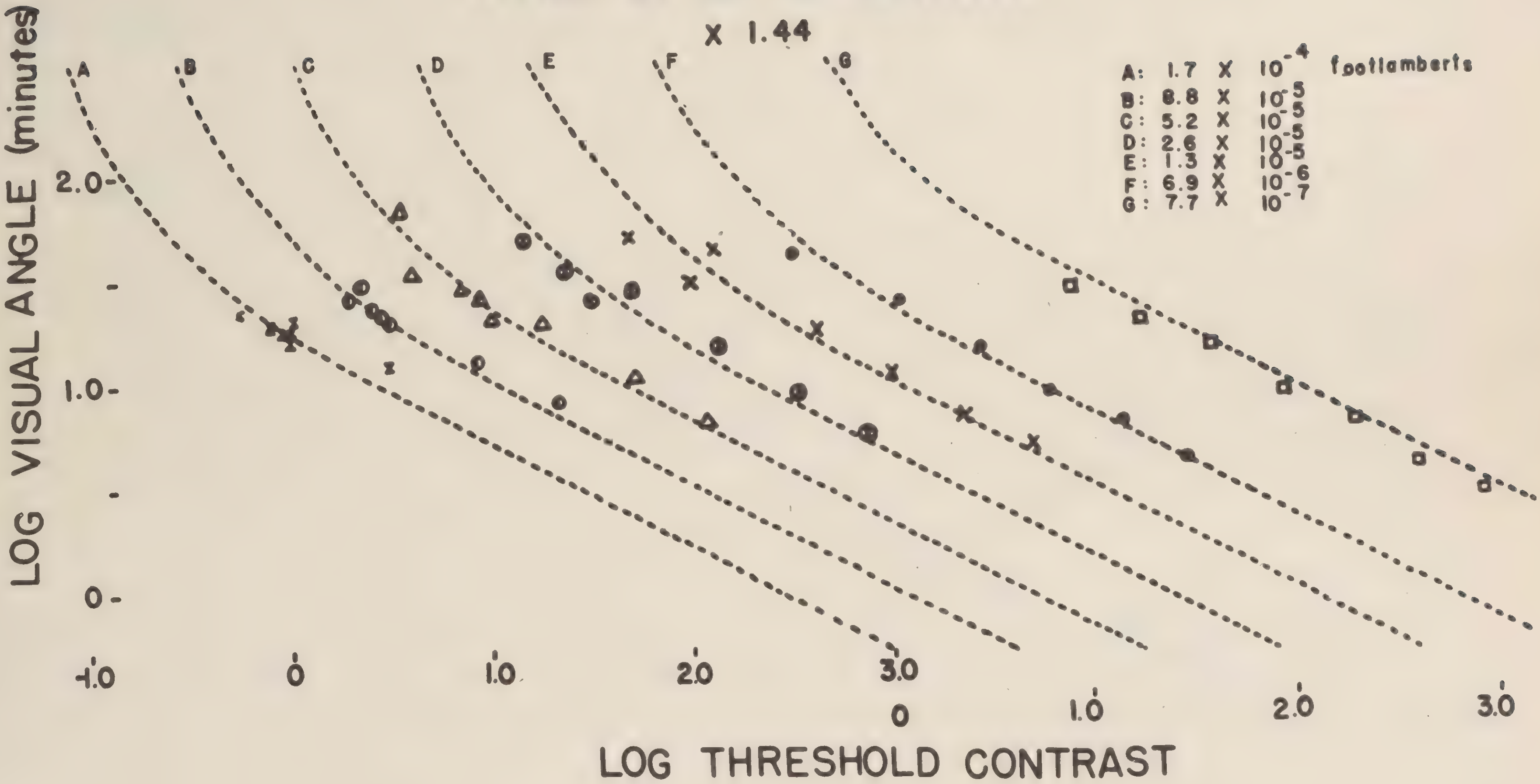


FIG 15

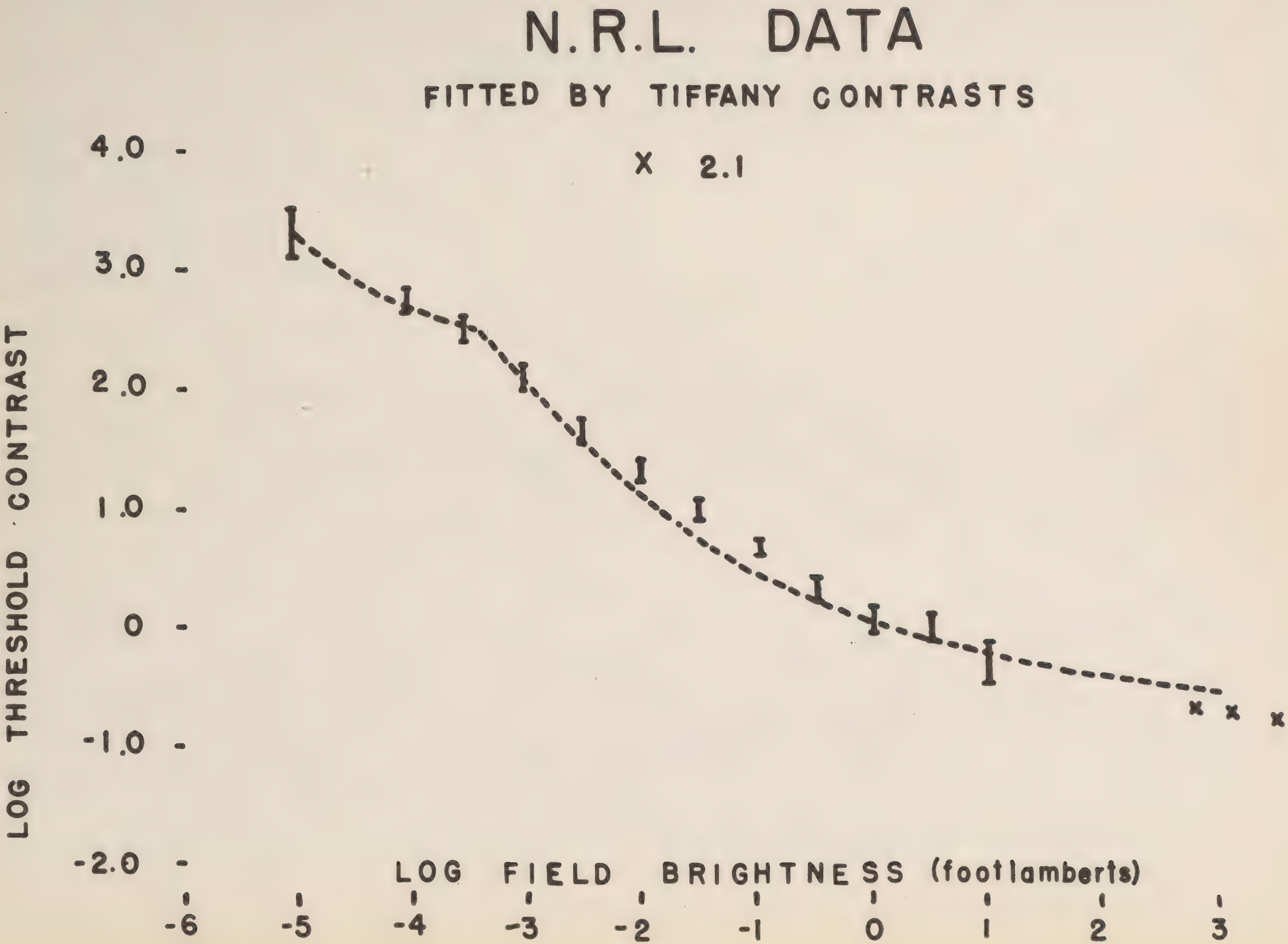
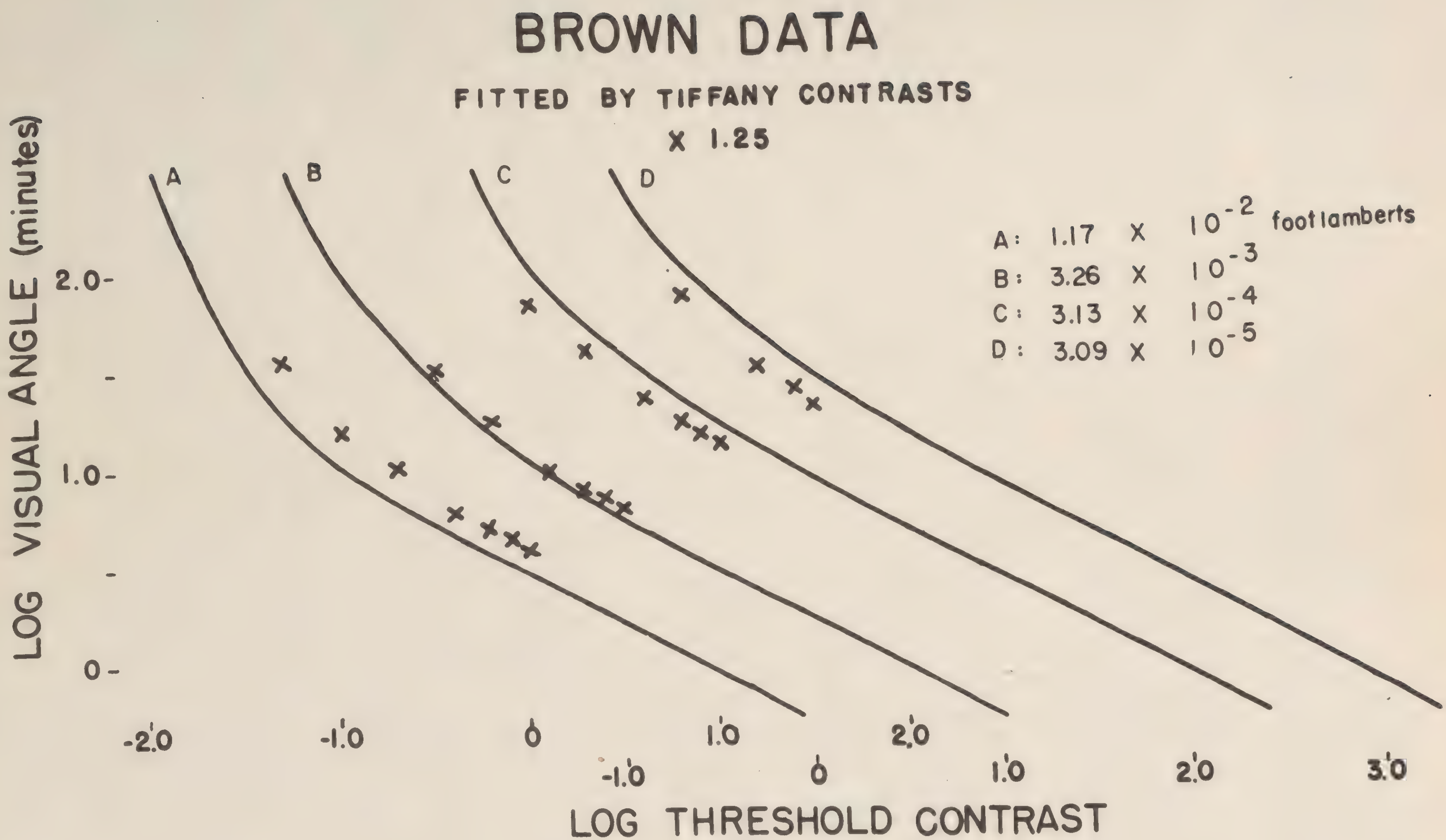

N.R.L. DATA
FITTED BY TIFFANY CONTRASTS
X 2.1
LOG THRESHOLD CONTRAST
4.0
3.0
2.0
1.0
0
-1.0
-2.0
LOG FIELD BRIGHTNESS (footlamberts)
-6
-5
-4
-3
-2
-1
0
1
2
3

FIG 16



BROWN DATA
FITTED BY TIFFANY CONTRASTS
X 1.25
A
B
C
D
A: 1.17 X 10^-2 footlamberts
B: 3.26 X 10^-3
C: 3.13 X 10^-4
D: 3.09 X 10^-5
LOG VISUAL ANGLE (minutes)
2.0
1.0
0
-2.0
-1.0
0
1.0
2.0
-1.0
0
1.0
2.0
3.0
LOG THRESHOLD CONTRAST

FIG 17

D. Comparison With Other Data

During the war, research programs were conducted elsewhere in which various portions of these conditions were investigated. Excellent agreement is obtained between these experimental data and the Tiffany results reported today, when allowances are made for differences in experimental procedure.

A study of dark targets at low brightnesses was made by the Dartmouth Eye Institute, under contract with NDRC, Section 16.1. The observers were allowed a six-second period in which to locate a target presented in any of four possible positions. Tiffany data are available in which nearly identical experimental conditions were used. Excellent agreement was obtained, as is shown in Figure 14.

Observations have been made at the University of Rochester and at the Naval Research Laboratory in which the observers had an indefinitely long time to search for the target. In each case, the observers adjusted the stimulus to a fixed point on the probability function. Agreement between these data and the Tiffany data with indefinitely long search can be obtained when allowance is made for the difference in experimental procedure.

The Tiffany probability curves were used in determining the correction to be made in order to bring the data into agreement. A factor is computed by which Tiffany contrast values must be multiplied to compensate for the difference in probability at the threshold.

In the case of the Rochester data, excellent agreement is obtained when the appropriate correction is made. Figure 15. These data represent a careful investigation of the brightness range between 1×10^{-4} and 1×10^{-6} footlamberts.

The NRL data are in excellent agreement with corresponding Tiffany data after allowance has been made for the difference in probability at the threshold. Figure 16. Extensive investigations were made with a 1 minute target for a wide range of field brightnesses.

A study of dark targets at low brightnesses was made by Brown University, under NDRC Section 16.1, utilizing a 30-second search. This represents a condition intermediate between Tiffany 6-second data and Tiffany data with indefinitely long search. Otherwise, however, the procedure at Brown corresponded closely with that at Tiffany. The Brown data are well fitted by the most appropriate Tiffany contrast values after approximate allowance has been made for the difference in search time. Figure 17.

[redacted]

In conclusion, an extensive body of experimental data has been reported. The precision of the Tiffany results and the excellent agreement between data obtained at various laboratories makes it possible for the human capacity for visual detection to be considered a well-determined variable contributing to the visibility of targets.

IV. THE CALCULATION OF LIMINAL TARGET RANGES
Dr. S. Q. Duntley*

From the outset of the researches on visibility by the N.D.R.C. Camouflage Section, it was the basic plan to separate the study of the limitations upon visibility imposed by the atmosphere from the study of the limitations on visibility imposed by the properties of the human eye. The former were studied outdoors by means of physical measurements; the latter were studied indoors by psychophysical methods under conditions which were carefully controlled. In order to predict the visibility of naval or military targets, it is necessary to combine the information so obtained. This can be done by calculations using the method of successive approximations. Such calculations are impractical for routine use because of their time-consuming nature. A simple type of nomographic chart illustrated by Figure 2 has been evolved for avoiding the calculations, and a set of such charts has been constructed for circular and rectangular targets at all levels of adaptation brightness from full daylight to darkest night. The nomographic visibility charts will appear in the forthcoming Camouflage Volume of the Summary Technical Report of N.D.R.C.

V. THE EFFECTS OF THE ATMOSPHERE ON THE PERFORMANCE OF OPTICAL INSTRUMENTS
Dr. A. C. Hardy
(presented by Dr. S. Q. Duntley)

Telescopes and binoculars are used for two distinct types of visual tasks: (1), to enable objects which are visible to the naked eye to be seen better; and (2) to enable distant objects to be sighted at a greater range than is possible with the unaided eye. When used for visual tasks of the first type, the atmosphere imposes the same limitation whether an optical instrument is used or not. In this case, the effect of a perfect instrument is to make the image appear M times larger, where M is the magnifying power. This is not equivalent to making the object appear M times closer, because the atmospheric effects are still present.

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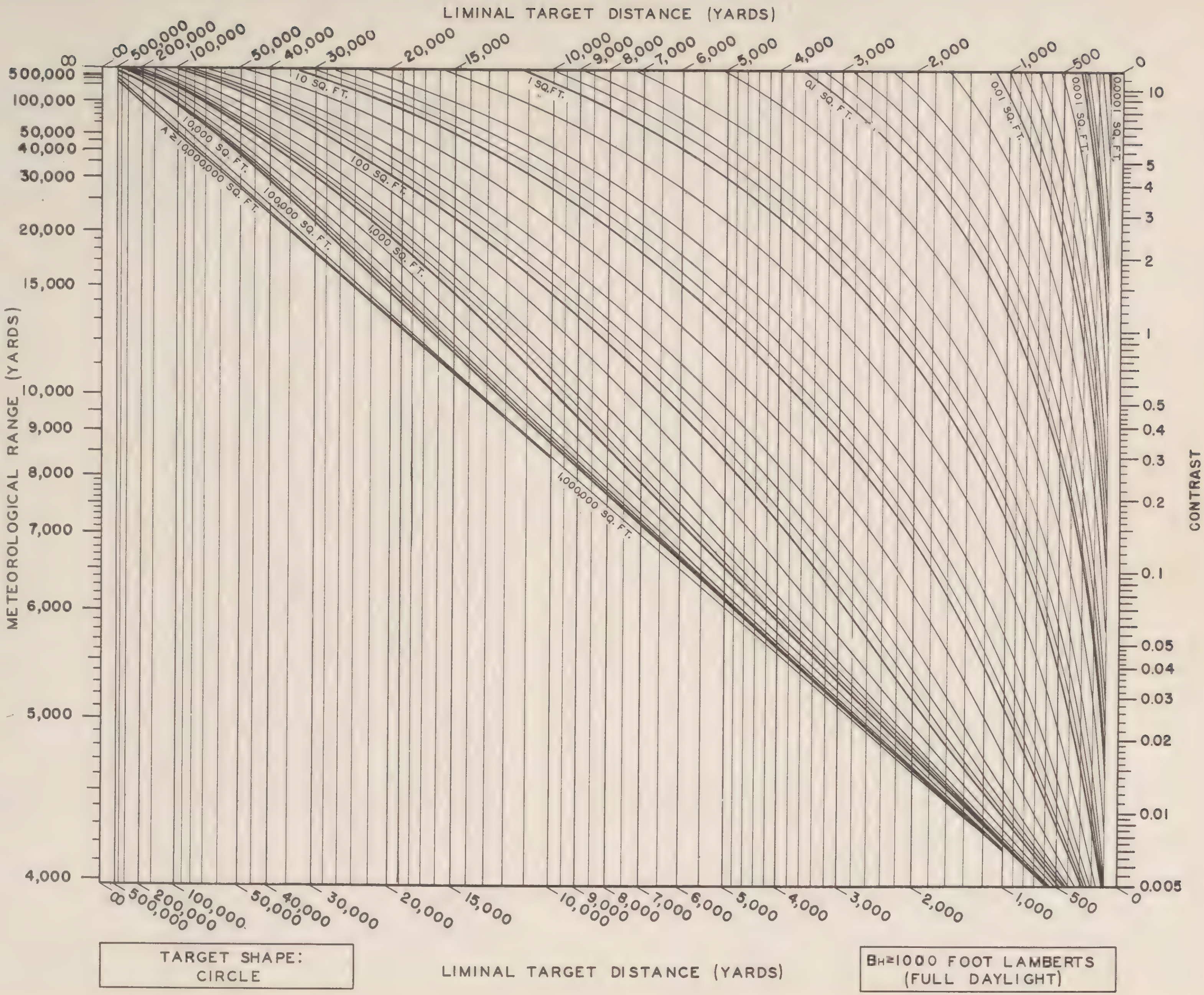
* A complete discussion of this topic will be found in the Summary Technical Report of N.D.R.C., Camouflage Volume.

[redacted]



~~Figure 3.2~~

FIG 2

[redacted]

This paper was concerned primarily with optical instruments used for visual tasks of the second type; that is, for searching for objects too distant to be seen with the naked eye. If no atmosphere were present, binoculars having a magnifying power M would enable an object to be seen M times further away. However, the effect of the atmosphere is to decrease the apparent contrast of the target as the target distance increases. Therefore, the amount by which even perfect binoculars can increase the sighting range depends upon the manner on which the eye of the observer is willing to "trade" the increase in apparent size for a decrease in apparent contrast. An equation showing the increase in range afforded by perfect instruments under the most favorable conditions was presented. Two different graphical representations of the equation were shown, and typical cases were discussed. It was concluded that even the small amount of atmospheric haze encountered during what is commonly called "clear-to-very-clear weather" reduces the amount by which binoculars increase the sighting range to a value far below ordinary expectations. The equation also indicates that except in extraordinarily clear weather or in the case of objects liminally visible to the naked eye at only very short distances, relatively little is to be gained by instruments of high magnifying power over instruments of low magnifying power.

VI. VISIBILITY OF TARGETS ON THE GROUND *

Dr. S. Q. Duntley

In this paper, which was not presented because of lack of time, the equations describing the reduction of target contrast by the atmosphere were extended to include the case of light traveling through the atmosphere along slant paths. In so doing, an optical standard atmosphere has been assumed, but methods have been developed which enable non-standard atmospheric conditions to be dealt with. The nomographic visibility charts presented in an earlier paper can be used to predict the visibility of targets on the ground provided the data entered on the chart are properly adjusted in accordance with the laws of the attenuation of contrast by the atmosphere along slant paths. By means of data on the reflectivity of natural terrains secured with the spectrogeograph, it is possible to approach the design of camouflage by engineering methods.

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* A complete discussion of the topic will be found in the Summary Technical Report of N.D.R.C., Camouflage Volume.

R[redacted]TED

DISCUSSION:

Dr. O'Brien commented upon the performance of optical instruments as reported by Dr. Duntley. He emphasized that in practice there are many conditions in which clear atmosphere and small targets exist, for which the range of detection is markedly increased by the use of binoculars.

Dr. Duntley reiterated his belief that under many conditions a low-power binocular would be very useful in search. He emphasized that high-power binoculars are extremely useful for obtaining a "better look" at a target which has already been detected, but that the evidence reported in his paper indicates a discouraging increase in threshold range with binoculars under many conditions.

Comdr. Ballard commented that both the Germans and the Japanese employed optical instruments with much higher magnifications than those used in this country.

Col. Alexander reported that he had attempted to use some of the high magnification instruments developed by the Japanese under field conditions. He commented that the heat waves rising from the deck of the ship were the only objects clearly discernible through the instrument.

Comdr. Ballard agreed that the Germans had decided that extremely high power optics were not worth the cost in manpower.

Dr. Duntley cautioned the members against interpreting his remarks to apply to cases of aerial observation. He emphasized that report dealt with horizontal atmospheric scattering only. The final paper which had been scheduled, but which was not delivered because of lack of time, concerned vertical atmospheric scattering.

In response to a question concerning evidence on the increase in threshold range resulting from color filters, Dr. Duntley emphasized that in general brightness contrasts dominate naval problems. The small color contrasts which are available can be neglected for most cases, especially for the long ranges usually encountered. Although special effects are sometimes possible through color filters, in general the effect of a color filter can be reduced to its effect in enhancing brightness contrast.

Dr. Tousey emphasized the difficulty in applying the visibility data obtained at Tiffany because of the inadequacy of present field methods for determining the condition of the atmosphere. The nomographic charts presented by Dr. Duntley emphasized that under many circumstances the most critical factor is the state of the atmosphere.

Dr. Tousey commented further that under many circumstances the atmosphere is extremely clear, in which case binoculars are often useful even for increasing the range of detection of targets.

Dr. Hartline expressed the belief that the binocular studies conducted by Section 16.1 in the laboratory, together with the treatment of atmospheric effects formulated by Section 16.3, might lead to a solution of the problem of binocular performance in the field. He emphasized the difficulty of interpreting factors such as binocular vibration but indicated that basic visibility data, such as the Tiffany data, were useful in evaluating the effect of vibration in terms of the smeared retinal image.

Dr. Neuberger asked whether data were available concerning the visibility of moving targets.

Mr. Blackwell reported that no such investigations had been made at Tiffany. He felt that an answer would be available when investigations were made to determine the relation between target exposure and threshold contrast with targets at various points in the visual field. He stated that the mere fact of motion would probably not prove important in determining the visibility of targets.

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PRELIMINARY REPORT ON FIELD TESTS OF OPTICAL INSTRUMENTS

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PRELIMINARY REPORT ON FIELD TESTS OF OPTICAL INSTRUMENTS

W. S. Verplanck, Lt. (jg), USNR

Since analysis of the data which were obtained in the experiment is not complete, the results cited in this report are not to be taken as final. It is our business now to describe the methods employed, to indicate the scope of the work accomplished, to report preliminary results obtained, to outline the full analysis proposed, and to evaluate the possibilities of field tests such as this.

The original plan of the tests called for work on six problems:

(a) Optical instruments for night use; shore and floating targets.

(b) Optical instruments for day use; shore and floating targets.

(c) Optical instruments for day use; aircraft targets.

(d) Daylight sky scanning procedures.

(e) Use of neutral and color filters for "haze penetration".

(f) Miscellaneous experimental problems.

Of these, parts (a) and (b) have been performed, and the data are being analyzed. Parts (c) and (d) have been dropped because of operational and personnel difficulties. Part (e) is now being run, and of the several items combined under (f), some were assimilated in (a) and (b), some were performed separately, and some were dropped.

This report will cover part (a) only.

Procedure:

The procedure followed in the night trials of optical instruments consisted primarily of the maintenance under observation of a series of targets by observers posted on the bridge of a DE, each using a different binocular or telescope.

Runs were made from ranges between six thousand and nine thousand yards, and from two directions, on a structure in Gardiner's Bay at the eastern end of Long Island, and on a submarine and SC stationed beyond it, one on each course. Several square black or white targets of varying size were erected on the top of the structure.

On each run, the observers reported in terms of three criteria of seeing: (a) when they first "glimpsed" each target (corresponding to a low frequency of seeing), (b) when they could see it all the time (high frequency of seeing), and (c) when they were able to positively identify it as the target in question. Responses were recorded in terms of the time elapsing from the beginning of the run, and were readily transposable into range by reference to regularly kept radar ranges and bearings, and to a DRT plot of the course run.

All night runs were made on moonless nights, without respect to cloud coverage, and in visibilities ranging from unlimited down to 3 miles. Operations were cancelled in extremely hazy, rough or rainy weather.

Six observers were posted on the signal bridge, and three on the gun deck immediately below. In trials of a given set of instruments, each of the six men on the signal bridge used each of six instruments in rotation over six runs. Simultaneously, the three men on the lower bridge rotated through two sets of three instruments each. In consequence, in six runs, 9 to 12 instruments could be tested simultaneously, each balanced with respect to observers, and all under a single set of conditions.

On each run, recording was performed by members of the group which observed on the following run. In this way, the subjects observed during one 35-40 minute run, and recorded during the next. This alternation facilitated scheduling and ensured adequate rest for the observers.

Table I lists the binoculars and telescopes which were tested in the night runs, togetherwith information on the manner in which they were used. Table II lists the number of nights on which operations took place, and Table IIB the sets of comparisons made during the night runs on which data will be forthcoming.

Statistical Method:

One student of the field has listed 60 (an underestimate, in all probability) variables entering into performances such as these. The analysis of variance design permits the partialling out of sources of variability extraneous to those under investigation. The Latin Square design was therefore followed, and the hand-held 7 x 50 x 7.1 Navy binocular was included in each square as a standard reference with which each other instrument compared. This method made possible a comparison on a single set of six runs of five instruments with the basic 7 x 50 x 7.1, with subject variance and run variance eliminated for this particular comparison. In six runs then, the full statistical analysis is obtained on each target on which results

are complete; these target by target results in turn are summated. A final step, to be taken when analysis of separate squares is complete, will synthesize results from square to square, taking into account differences in findings between squares owing to visibility, personnel, wind, cold and other relatively uncontrollable variables.

Figure I is a single raw data sheet, copied exactly as it was turned in by one subject on one run. The data themselves, consist in the numbers of 15-second intervals intervening between the beginning of the run, and the subject's report of having spotted each target to each criterion of seeing. Those values are transcribed by means of range sheets, which give the range in yards of the targets at 30-second intervals, into actual ranges, and are then entered on statistical analysis sheets, of which there is one for each target. One or two items of data are found missing from the raw data sheets, due to failure of the subject to see the target, or to report it if seen. Such gaps in the data prevent statistical analysis of all results on the target missing, therefore a procedure has been set up to take them into account.

Certain of such missing values are filled in on the basis of the mean proportional ranges for all targets and all subjects in the square of "first glimpse", "100% seeing", and "positive identification". If "first glimpse" range is taken as 100%, the latter two ranges closely approximate 75% and 62½% respectively. Three criteria were applied in using these fill-in values. No values were filled in from those of more demanding criteria of seeing. Finally, of course, no values were filled in from one target to another.

The completed data on each target are next statistically treated, so that inter-subject, inter-run, and inter-instrument variance are separated out, and the error variance, that is, the variability not attributable to these three, obtained. From the mean ranges, and the error variance the standard error of the difference is obtained. For each instrument three estimates of superiority or inferiority to the 7 x 50 x 7 are now made*, and the value of the statistical constant "t"

----

* These estimates are made as follows:

(1) $t = (M_B - M_{7 \times 50})$/ SE diff. (where M is the mean range obtained on a given target by binocular B and by the 7 x 50.

(2) $t = (M_B - 1.15\ M_{7} \times 50)$/ SE diff.

(3) $t = (M_B - 1.25\ M_{7} \times 50)$/ SE diff.

In other words, the performance of the 7 x 50's is hypothetically varied. The hypothesis may vary, of course, with the performance of the binocular, e.g., in the case of an inferior binocular, the hypotheses were .50 M 7x50 and .75 M7x50.

for each such difference is computed. This "t" value is a measure of the reliability of the difference. The probabilities of occurrence of these three values, obtained on each criterion of seeing, are now plotted on probability paper, and a straight line is drawn.

Thus on a single sheet of probability paper, there are plotted for a single instrument a series of straight lines giving estimates of the instrument's performance on each target, and to each criterion of seeing, with respect to the 7 x 50 x 7 binocular. This short-cut gives us an immediate evaluation of the probability of all possible relative performances on each target and to each criterion.

This plot, on a large number of squares has consistently shown that "first glimpse" and "100% frequency" of the largest target, the fort itself, behave differently from the remainder of the targets. Therefore they were not included in the analysis reported here but are reserved for treatment when the sightings of the submarine and 2C have been similarly analyzed.

Now at 10% intervals along the abscissa, values of "t" corresponding to the interpolated probabilities read off the graph are averaged, and the probability of this average "t" is now looked up in a "t" table, so that a single curve representing data on all the targets to each criterion of seeing can be drawn for each instrument. Figure 11 gives sets of such curves for two different squares.

The abscissa gives the percentage of the basic 7 x 50 reference range about which we ask a question: What is the probability that binocular X will give a range 50% greater than that given by the 7 x 50? The ordinate gives the answers: 93 in 100 that the 20 x 120 will do so, 81 in 100 for the 25 x 100, 21 in 100 for the 10 x 80, 8 in 100 for the 10 x 70, 5 in 100 for a 21X telescope, and .000... in 100 for the other instruments.

This procedure necessarily involves a great burden of statistical work - at the present time, 8/9 of the calculations for this basic treatment are completed, but several thousands of linear and summary graphs must be done.

However, calculations and plots are complete on eight of the twenty-six 6-run squares. In Table III are given the .50 probability ranges of the instruments tested in these squares.

Each square, it is obvious, does not give the same estimate of a binocular's performance. There are ample reasons for such variability from square to square, and these will be teased out in the final analysis of the data.

Obvious sources will include:

(1) Visibility (a high power instrument will suffer relative to the 7 x 50)
(2) Wind (instruments on the windward side will perform less well)
(3) Observing group

Preliminary Results:

It has been possible to make certain preliminary analyses, pending completion of the basic statistical program outlined above.

Visibility: Visibility data are summarized in Table IV. Mean values for all targets give 25% greater range for B visibility over C, and 50% greater ranges for A over C.

Analysis according to visibility is still, however, far from complete, and no final values may be given.

Courses: Data on the courses are presented in Table V for two visibility conditions. There are insufficient data in B visibility to permit analysis.

Analysis on all targets shows no difference between the courses under A visibility, and a slight but insignificant ($.3\sigma$) difference under C visibility, in favor of the .065 course. These data indicate that horizon lights did not provide invalidating cues to the observers, since the lights are worse on the Constellation Rock course than the .065 course, and since they played no role under C visibility.

Again, a more complete analysis will be made.

Vibration: All runs were made at 8 - 9 knots, with the exception of those in which vibration was desired. These last were made at 17 knots, which yielded a maximum perceptible vibration. High speed cut down 7 x 50 x 7.1 H-H- binocular ranges to 50% and even 25% of their value on the slower relatively vibrationless runs.

Search: It has been anticipated that our data on search for the S/M and SC might be invalidated by reason of the narrow arc within which the targets appeared (seldom further than 5° from the bow). In 40 sightings, the submarine was sighted at the 100% criterion at 2,850 yards (± 670 yards) and was "positively identified" at 2,310 yards (± 670 yards). The former value may be compared with the 2,610 yard average of 86 "sure sightings" obtained under comparable brightness, speeds of closing, and target angles, by Comdr. D. R. E. Brown. Again, analysis is far from complete.

Variability of 7 x 50 x 7 Binoculars: The data given in Table III on six 7 x 50 x 7 binoculars indicate the extent of this problem. The problem is a little distorted by these results, since, by chance, the best binocular was used as the reference binocular. Individual 7 x 50's vary more than would be expected. Nevertheless, these differences should correlate with optical properties of the glasses. They must also be taken into account in evaluating the results of each square.

Exit Pupil: The dark adapted pupils of the observers were measured by Dr. Irving Wagman of the Johnson Foundation. These 46 men averaged 6.83 mm with a standard deviation of 1.03 mm. The range was from 4.6 mm to 8.9 mm. These data offer an opportunity to evaluate calculations which have been made on the relative advantages of 5, 7, and 8 mm exit pupils for observers of varying pupil sizes.

Naked Eye: Data available to date on the naked eye show ranges approximately 40% of the hand-held 7 x 50 x 7.1 binoculars. Here again, the results of Comdr. Brown's field data are duplicated.

Comment Sheets and Rating Scales: At the end of each run, each observer was asked to mark as excellent, good, fair or poor, the instrument which he had just used with respect to several possible standards. These have been tabulated, instrument by instrument, and the percentage of responses in each category determined. A summary score for each instrument was obtained by a simple formula, and an order of preference established.

Several days after the end of the October series, 24 men who had used a wide variety of binoculars and telescopes were asked to place them in rank order of preference.

Rank order correlations have been obtained between the latter rankings and the summary order of preferences. These data are presented in Table VII. The correlations are strikingly high, and the rankings are remarkably close to the actual performance of the binoculars. The data suggest that the observers who have had sufficient and systematic experience with a series of binoculars and optical instruments are able to evaluate them with good precision.

Position on Bridge: In the early runs, it was possible to rotate the position of each binocular on the bridge throughout the six runs of a square. However, with the use of mounts, this was no longer feasible.

Analysis by position is of importance since the performance of a particular glass may depend on the position in which it was placed, e.g. the Ship's Telescope, which was in

[redacted]

position 1 may have performed poorly because in all the squares in which it appeared, position 1 was exposed to the wind. Again, location in position 1 may improve the performance of a hand-held binocular, since it was the most difficult to supervise and data on a hand-held glass might actually be data on a hand-held-rested glass!

From another point of view, the variability of data obtained in positions 1 and 6 as compared with that of positions 2, 3, 4, and 5, will indicate the influence of one subject's reports on another, since these stations were isolated from the rest.

Results to date show:

(a) On early runs, there was no differential in mean range among positions. On all these runs there was no appreciable wind.

(b) On all runs, variability is the same in all positions.

Focuses: Focuses were recorded on approximately 40 men on a variety of instruments. Results are typical of self-adjusted determinations of focus: the mean is approximately -1d, the standard deviation about .7d. After 10 weeks of observing, two men complained of eyestrain and were prescribed necessary glasses. Both these men had used excessively negative binocular focuses. By the method of self-adjustment, one averaged $2\frac{1}{4}$ for both eyes, and by the constant method -1 d, a suggestive finding.

Interaction: Twelve men were run on three very similar glasses (10 x 50 x 7, 7 x 50 x 7, 7 x 50 x 10) in order to determine if some do relatively better with one glass than another. The finding was positive: three performed better on the 7 x 50 x 7, four on the 7 x 50 x 10, and five on the 10 x 50 x 7. Differences in ranges, however, were small, the 7 x 50 x 10 being slightly better than the 7 x 50 x 7, and both better than the 10 x 50 x 7. An attempt will be made to relate this finding to other individual differences, e.g. in training and in pupil diameter, and to the observer's comments on the glass.

The Monocular vs the Binocular: In an early series, the 7 x 50 x 7 was used both monocularly and binocularly. Monocular ranges were some 15% short of binocular ranges.

Criteria of Seeing: It will be recalled that three criteria of seeing were employed on each target: "first glimpse", which, it was expected, would correspond to a low frequency of seeing, "100%", corresponding to a high frequency of seeing, and "positive identification" which should be a different category of response.

[redacted]

[redacted]

Just what criteria the subjects set up for themselves in each case, one cannot say. However, each was consistent with himself, and the data do not indicate that these criteria shifted.

These data may be compared with equivalent data obtained at Brown, and at Dartmouth (Table VI).

Statistical Work Planned:

Besides refinement and completion of the preliminary results sketched above, it is expected to provide results on the following problems:

(1) Visibility: A most critical problem. Since the evaluations of visibility used are considered unsatisfactory, several approaches to the problem will be made, in order to find appropriate factors to apply to each square.

(2) Fixed Focus: Relative ranges on 8 x 60's fixed at -2 diopters and -1 diopters

 (a) for the whole population
 (b) for populations selected on the basis of self-adjusted focus.

(3) Individual Differences: Data have been obtained on (a) the Radium Plaque Adaptometer, (b) the Orthorater, (c) the RCN Adaptometer, (d) pupil size, (e) General Classification Test, (f) focus, (g) experience, and (h) training.

 Tests of the data will be made to establish whether significant individual differences in performance exist. If the results are positive, correlations will be made with the variables indicated above.

 It should be noted that individual differences among observers will be somewhat obscured by the practice of pairing observers and recorders, since some recorders were more skilled than others.

(4) Exit Pupil Series: A comparison of performance on the 10 x 50 x 7, 10 x 70 x 7, 10 x 80 x 8, and the 6 x 35 x 8, 6 x 42 x 8, 6 x 50 x 8 will be made for the whole population, and for individuals of small and large pupil diameter.

(5) Power Series: A second comparison on the 6 x 42, 7 x 50, 9 x 63, and 10 x 70 and 20 x 120 will be made. Secondary analysis with respect to ship's vibration and visibility will follow.

[redacted]

(6) Mount Series: The relative effectiveness with and without vibration, of hand-held, hand-held rested, mounted, and "vibration free" mounted 7 x 50 x 7's will be established.

(7) Discrepancy Analysis: Run-by-run, night-by-night, subject-by-subject analysis, directed at obtaining the most valid results must be completed for solution of discrepancies among squares.

(8) Wind: Analysis of position effect, as related to velocity and direction of wind is necessary.

(9) Target Analysis: Computation of mean 7 x 50 x 7 ranges for each target will be followed by calculations of mean visual angles subtended. These results will be related to laboratory data.

(10) Eye Guards: Determination of effectiveness of eyeguards will be possible by comparison of 7 x 50 x 10 with its standard eyeguard, and with the adapters built at New London to yield practical eye distances equivalent to those of the 7 x 50 x 7 (it had been planned to provide eyeguards for all instruments, but it was technically impossible to do so).

(11) Section-by-Section Analysis: A comparison of one section of men with no experience as lookouts, and no training, with one of 1-2 year men will be made.

(12) Sky Brightness: An attempt will be made to determine the degree to which variations in the sky-sea brightness ratio, and in sky brightness, affected the results.

(13) Search: Search data on the submarine and SC will be fully worked out. Data on first glimpse of the fort, and 100% on the fort suggest that binoculars differ less as instruments for search than for examination of targets of known position.

(14) Comparison with Other Data: An attempt will be made to relate all the present findings with all data on binoculars and on visibility available. Pertinent checks may be made on:

(a) Binocular advantages
(b) Visibility and range
(c) Variability of subjects
(d) Individual differences

[redacted]

GENERAL CONCLUSIONS

The results available to date are most encouraging. It is apparent that the procedures followed in this field experiment will give quantitative answers to the problems posed.

In some respects, one could wish better data. If, for example, the time and personnel had been available so that all six runs of a square could be made under near-identical conditions, data would be directly available on many critical problems of visibility and instrument performance.

Certainly, one may be reasonably certain, that the setting-up of such a field project, on a permanent basis, with permanent personnel, and ample time to gather data under a wide variety of conditions will amply repay in field results the time and expenditure involved. Instruments, timing, methods, selection methods, procedures, could all be evaluated in actual practice, and there need be no questions raised of the validity of any laboratory findings.

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TABLE I.

BINOCULARS AND TELESCOPES TESTED

(Night Series)

Mtd:	Mounted	VFA:	Vibration-free alidade mounted
HH :	Hand-held		
Mon:	Monocular	EG :	Eyeguard

	BINOCULAR OR TELESCOPE	CHARACTERISTICS	MODE OF USE			
(1)	M-12 Panoramic Telescope	4 x 17 x 10	Mtd.			
(2)	Telescope Mk 79 Mod.0	4 x 28 x 10	"			
(3)	Telescope Mk 50 Mod.1	6 x 30 x 8.6	"			
(4)	Telescope Mk 60 Mod.	6 x 33 x 8	"			
(5)	Binocular Mk 43 Mod.0	6 x 42 x 12	"	H-H		
(6)	∅Telescope Mk 51 " 0	6 x 30 x 7	"	Mtd. 6x33	Mtd. 6x42	Mtd. 6x33
(7)	Binocular Mk 32 " 2	7 x 50 x 7.1	"*	HH*	HHR*	Mon VFA*
(8)	Binocular Mk 41 " 0	7 x 50 x 10	"	HH	HH	EG
(9)	German Binocular	8 x 60 x 5 (?)	"	HH(-1d)	HH(-3d)	
(10)	Binocular Mark 37 Mod.0	9 x 63 x 5.7	"	HH		
(11)	Binocular " 36 " 0	10 x 50 x 7	"*	HH*		
(12)	Johnson Foundation Experimental	10 x 70 x 7		HH		
(13)	NDRC Pilot	10 x 70 x 7	"			
(14)	German Binocular	10 x 80 x ?	"			
(15)	NavGun XPS-1	16 x 96 x 3.2	"			
(16)	Ship's Binocular Mk 1 Mod.0	20 x 120 x 3	"			
(17)	Ship's Telescope Mk 1 Mod.0	21 x 76 x 2.8	"			
(18)	NavGun XPS-1	24 x 96 x 2.2	"			
(19)	German Binocular	25 x 100 x 3.6	"			

∅ By nomenclature a telescope, in fact a binocular

* Tested at speeds of 9 knots and 17 knots. All others tested at 9 knots.

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[redacted]

TABLE II

SUMMARY OF OPERATIONS

(Night Series)

A Total Possible Nights for Operation (Sept. 4-Dec. 9) 43

Successful Operating Nights	23
Cancelled, weather	13
Cancelled, mechanical difficulty DE)	4
Cancelled, other causes	3

B. Summary of Comparisons Run.

Comparison	Runs in Square	No. of Sections; No. of Repetitions by each Sec.
Interaction Series	12	1 x 1
Hand-Held Binoculars	6	3 x 2; 1 x 1
Mounted (Low Power)	6	4 x 1
Mounted (High Power)	6	4 x 1
Type of Mount (9 kts)	6	5 x 1) One Section
Type of Mount (17 kts)	6	2 x 1) in Common
Variability of 7 x 50's	6	2 x 1
Exit Pupil Mk 91	6	2 x 1
Fixed Focus (-1d, -2d)	3	4 x 2
Eyeguard	3	4 x 2
Mk 91 - Mk 60	3	2 x 1
Exit Pupil (Mk 91)	3	2 x 1
6 x 42 (9 kts)	3	3 x 2
6 x 42 (17 kts)	3	2 x 3
10 x 50	3	4 x 1
Mt-Field (5.6°)	3	4 x 1
" " (10°)	3	4 x 1
" " (12°)	3	4 x 1

Total Squares:

12-run squares:	1
6-run squares:	26
3-run squares:	48

Total Runs: 177

[redacted]

[redacted]

TABLE III

SAMPLE RESULTS

(50% Probability Ranges)

INSTRUMENT	MA	MB	M(1)D	M(1)E	BA	B(1)X	PD	VD
Basic hand-held 7x50	100	100	100	100	100	100	100	100
Telescope Mark 79-0 4 x 28 x 10	59	45	49	46				
Mark 50-0 6 x 30 x 8.5	51	47	69	27				
Mark 60 6 x 33 x 8	63	61	53	58		60		
Bin. Mk. 32-1 HH 7 x 50 x 7								77
Bin. Mk. 32-2 HH 7 x 50 x 7								87
Bin. Mk. 32-3 HH 7 x 50 x 7								92
Bin. Mk. 32-4 HH 7 x 50 x 7								71
Bin. Mk. 32-5 HH 7 x 50 x 7								93
Bin. Mk. HHR 7 x 50 x 7					112			
Bin. Mk. VFA 7 x 50 x 7					116	108		
Bin. Mk. 36 10 x 50 x 7					101			
Bin. Mk. Mtd. 10 x 50 x 7	110	110			128	106		
NDRC Pilot 10 x 70 x 7	129	110	105	135		111		
German 10 x 80 x ?							135	
NavGun XPS-1 6 x 96 x 32							116	
Ship's Binocular Mk 20 x 120 x 3			120	184			180	
Ship's Telescope Mk-1 21 x 76 x 2.8							73	
German 25 x 100 x 3.6							169	

[redacted]

TABLE IV

Mean Visibility Ranges (yards) : All Data on 7 x 50 x 7.1 H-H
(N = 82 matched observers)

Visibility	Tgt: Fort Crit: P.I.	Tgt: Radar Screen Crit: 100%	Tgt: 8x8 Black Crit: "Glimpse"
A. (10 miles)	3700 (1.50)	3000 (1.30)	3707 (1.46)
B. (5-10 ")	2970 (1.24)	2595 (1.16)	3000 (1.24)
C. (0-5 ")	2470 (1.00)	2310 (1.00)	2530 (1.00)

TABLE V

Mean Course Ranges (yards) : All Data on 7 x 50 x 7.1 H-H
(N = 24 matched observers)

Course	Tgt: Fort Crit: 100%		Tgt: Radar Screen Crit: "Glimpse"		Tgt: 8x8 Black Crit: "Glimpse"	
	Vis. A	Vis. C	Vis. A	Vis. C	Vis. A	Vis.
Constellation Rock (210)	6800	3700	4000	2400	3300	2500
065 Course	6900	4200	4500	2900	3500	2800

TABLE VI

RELATIVE RANGES FOR CRITERIA OF SEEING

	Relative Range Frequency of Seeing 1%	Relative Range Frequency of Seeing 50%	Relative Range Frequency of Seeing 100%
Brown Data	100	73	57
Dartmouth Data	100	50	31
	"First Glimpse"	"100%"	Positive Identification
New London Data	100	75	62

[redacted]

TABLE VII

SUBJECTIVE EVALUATIONS OF INSTRUMENTS

INSTRUMENT	Mean Rank	Evaluation Scores "Search"	"Recog"	"Steadiness"	Ease of Handling
S.B. Mk-1-0 20x120x3	1.4	106	110	117	112
Mk 35-0 Mtd. 10x50x7	3.7	75	66	82	100
NDRC P Mtd. 10x70x7	4.2	14*	56*	114*	41*
Mk 32-2HHR 7x50x7	5.6	88	65	76	100
Mk 32-2 HH 7x50x7	6.0	80	88	91	109
Mk 32-2 VFA 7x50x7	6.5	88	77	90	101
German 10x80x?		79	60	105	105
Mk 36-0 HH 10x50x7	6.6	72	63	76	106
Mk 41-0 HH 7x50x10	7.3	71	77	77	80
Mk 41-0 Mtd. 7x50x10	7.6	69	80	80	93
Mk 43-0 Mtd. 6x42x12		50	40	70	110
Nav Gun XPS-1 16x96x3.2		50	13	37	37
Mk 43-0 HH 6x42x12	8.7	37	40	69	85
Mk 37-0 Mtd 9x63x5.6		36	54	36	80
Nav Gun XPS-1 24x96x3.2		14	14	29	43
Mk 37-0 HH 9x63x5.6	8.9	9	54	55	73
German HH 8x60x?	10.4	-11	34	33	-28
Mk 32-2 HH 7x50x7 Mon.	13.8				
Mk-60 6x33x8	14.6	-51	-24	39	22
St Mr 1-0 21x76x28		-61	-62	0	-9
Mk 50-1 6x30x8.5	14.8	-81	-51	33	25
Mk 79 4x28x10	15.2	-52	-52	18	10
Naked Eye	15.8				
Rho (with Mean Rank)		.84	.77	.91	.73

The evaluation score is computed as follows:

2 x % "Excellent" % "Good" -% "Poor"

* Known to be in error, not yet checked.

[redacted]

[redacted]

FIGURE I

DATA SHEET

OBSERVER SHOEMAKER TIME: Start: 0058 BRIDGE POSITION 2

RECORDER FOLEY Finish: 0120 BINOCULAR 25 x 100

SECTION D NO.OF RUN 9 DATE 8 Nov. COURSE Constellation Rock

Eyesetting R - 1½
L - 2

TARGET	FIRST GLIMPSE	100% FREQUENCY	POSITIVE IDENTIFICATION	REMARKS:
(1) Fort	5	8	14	
(3) Radar	14	24	42	
(4) No. 1 (8'x8' Bl)	24	35	41	
(5) No. 4 (8'x8' Bl)	37	45	51	
(6) No. 3 (6'x6' Bl)	30	35	45	
(7) 8'x8' flat white	31	38	45	
(8) 16'x16' flat bl.				
(9) 4' x 4'				
(10) Flag Pole	52	53		
	Time Bearing	Time Bearing	Time Bearing	
SUBMARINE				
SUB CHASER	60 000	68 359	77 359	

[redacted]

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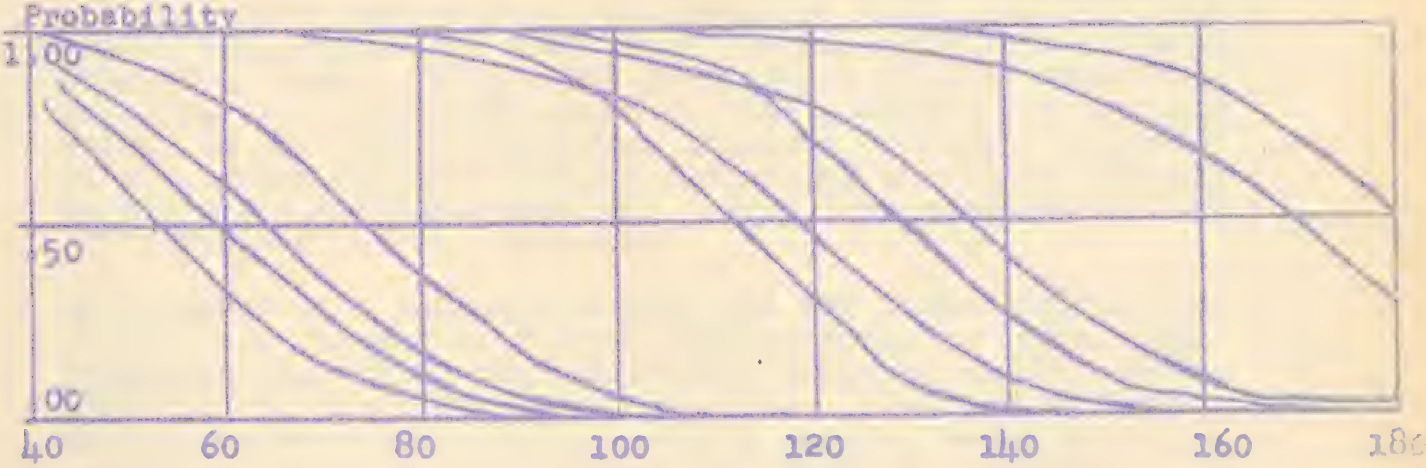
FIGURE II

SAMPLE RESULTS (2 Squares)



Percentage of Mean - 7 x 50 x 7.1 H-H Range

Curve	Instrument		Square
A	Mk 50-1	6 x 33 x 8.6	MA
B	Mk 79-0	4 x 28 x 10	MA
C	Mk 60	6 x 33 x 8	MA
D	Ship's Tel. Mk-1	21 x 76 x 28	PD
E	Mk 36 Bin. M	10 x 50 x 7	MA
F	NavGun XPS-1	16 x 96 x 3.2	PD
G	NDRC Pilot	10 x 70 x 7	MA
H	German	10 x 80 x ?	PD
I	German	25 x 100 x 3.6	PD
J	Ship's Bin Mk-1	20 x 120 x 3	PD

Information on Squares

Square MA

Section A

All Runs - A Visibility
4 on course 210
2 on course 065
8-12 knots wind on course
210 from 230
Speed: 9 knots

Square PD

Section D

All Runs - A Visibility
2 on course 210
4 on course 065
8-12 knots wind abeam, both
courses
Speed: 9 knots

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Discussion:

Comdr. Ballard commented on the great value of field tests in determining the design of optical instruments. He commented upon the origin of the studies reported by Lt. Verplanck. In a Vision Committee meeting, the need for field tests had been emphasized, and at the request of the Chairman of the Vision Committee, Comdr. Ballard had submitted a list of specific questions for immediate solution. The present study had its origin in the list of questions prepared by Comdr. Ballard. It was emphasized that various members of the Vision Committee participated in theplanning and initial experimentation in the study reported by Lt. Verplanck.

In response to a question whether the New London studies indicated any changes in doctrine for training in search, Lt. Verplanck emphasized that individual lookouts should not be permitted to focus their own binoculars. The proper focus should be determined for each man by careful tests and on subsequent occasions such a setting should be required.

Lt. Verplanck commented that the lookouts used in his experiment were able to rate the various binoculars extremely well, in terms of the final ratings based upon experimentation.

Lt. Verplanck emphasized that whereas the conclusions made by Dr. Duntley concerning the small increase in threshold range with increase in magnification may be correct, the nature of the increase in the probability of detection must not be overlooked. In practice, a 7-power binocular increases the probability of detection of a target by the factor 6.5.

Comdr. Ballard reminded the Committee that such factors as magnification, field of view, etc., do not wholly determine the performance of an optical instrument. The reduction of contrast due to the scattering within an optical instrument is a less well recognized determinant of performance. In order to investigate further the reduction of contrast a research program is being conducted at Pennsylvania State College.

Lt. Comdr. Pulling introduced Dr. Coleman, under whose direction the project at Pennsylvania State is organized.

Dr. Coleman described some of the experimental procedures being used in measuring the reduction of contrast by scattering in optical instruments. He revealed that a reduction of contrast of less than 2% was customary for "bloomed" instruments.

Mr. Blackwell stated that the Tiffany data indicate that a 2% change in contrast has an insignificant effect on range.

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Dr. Hartline and Dr. Hecht agreed with this comment and implied that the matter of scattering in optical instruments might be unimportant.

Lt. Comdr. Pulling emphasized that there are additional factors involved other than the reduction in contrast. Scattering within optical instruments reduces the sharpness of the physical gradient of illumination at the border of targets. Evidence is not available to permit evaluation of the effect upon visual performance of such a reduction in the sharpness of the contour.

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VISIBILITY OF SHIPS

AT NIGHT

Comdr. Dayton R. E. Brown
Code 342
Bureau of Ships, Navy Dept.
Washington 25, D. C.

[redacted]

VISIBILITY OF SHIPS AT NIGHT *

Dayton R. E. Brown, Comdr., USNR

FOREWARD

The initial purpose of this investigation was to determine how close a small U. S. "vessel x" could approach an enemy ship at night and remain unseen; to plot the area which would mark this safe limit of her concealment in every direction under given light and weather condition. Such areas were called Visibility Circles. We investigated these visibility areas by maneuvering our ships into them on clear starlight, clear moonlight, and overcast nights under conditions of excellent visibility, measuring the conditions as well as the ranges at which sightings occurred. Diagrams were drawn both from the friendly and enemy points of view, representing the visibility ranges for optimum conditions from the enemy's standpoint, since the lookouts were well-trained, rested, well-equipped and were told where to look to find the approaching "vessel x". Numerical data used to construct these diagrams are available in tables and graphs.

Of all the sightings made, (over 1,000) 680 taken by observers on surface ships, 10 by observers in airplanes and 12 by observers in blimps were considered dependable and used in constructing the diagrams, etc. When sightings were made, the light and weather conditions were measured as carefully as was possible during time of war, even though the observations were made in the friendly waters around Pearl Harbor. Simulated attacks were made on "target vessels", aboard which observers were posted. The runs were made at various speeds, so that the best speed for attack could be determined since sighting range was believed to be a function of the speed. Attacks were made from different points of the compass so that a comparison could be made of the difference in sighting ranges caused by the relative positions of moon, attacking ship and target ship since sighting range was believed to be an important function of the sky brightness. Bow-on (attacking) and broadside (passing) attitudes were both studied because we believed sighting ranges to be related significantly to size.

The rate of scan, the height of eye, performance of lookouts, effect of fatigue, use of binoculars and other factors of seeing were investigated to some extent under various sea conditions. By virtue of the measurements taken, not only

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* This paper summarizes experimental data presented more fully by Commander Brown in a forthcoming report. Graphs and illustrations referred to in this summary will be found in the more complete report.

of the ranges at which sightings were made, but also the thousands of measurements of light and weather conditions, speed of attacker and observing craft, aspect of the object seen, etc., it is believed that this investigation may contribute some new data to the science of seeing. But more important perhaps, it poses new practical problems and by the very lack of information to meet them, points to the necessity of some additional basic research and considerable applied research in the field of vision and visibility.

Three interim reports were given during the last two years of the war. The first, entirely qualitative, was based on hundreds of hours of aerial and surface observing. The second and third were interim reports which included much of the data contained herein and were reported in rough form but timely, so that they could be and were incorporated into Concealment Tactics while data was still being collected. Now that hostilities have ceased, the investigation may be of greater interest to aviators and meteorologists in connection with visibility forecasting. This information can also be used in the study of the visibility of common objects at night. Those interested in the science of seeing as applied to transportation and navigation may find some benefit in the measurements made at sea and in the air to compare with measurement of test objects observed in the laboratory.

Illustrations of what ships looked like near the limit of visibility were made from sketches and notes taken down at the time the sightings were made. It is hoped that these may prove of help in the instruction of ship lookouts and in more clearly describing to all seafaring men the conditions under which sightings are made at night.

STATEMENT OF FINDINGS

Seeing Ships at Night

This investigation showed first that trying to guess how far a ship can be seen at night will not give the answer. Guessing misses by 200 to 300%. Secondly, it showed that very few men know how to search, day or night, principally because they don't know what objects look like at the limit of the visible threshold, either to the unaided eye or in the field of binoculars. Nor do they know what physical factors determine what can be seen, how well, or how far. Hence, they do not know how best to search, observe or record what may be seen.

The author has found it somewhat difficult to draw pictures of invisible ships, but illustrations have been made which are an attempt to describe what "X vessels" did look like when near the limit of visibility, and what they looked like

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under the same light and weather conditions a few minutes later, after they had come in much nearer to the observer. A text accompanying the illustrations gives some figures on ranges and certain characteristics of the scenes which effected them.

Factors of Influence in General

In some cases, it is felt that the data are insufficient to encompass the real average performance. We know the record is incomplete principally in that only a few types of light and weather were investigated. But we have good assurance that further field studies will be made in the near future, both to obtain new facts and figures and the reasons for them.

We found, as we had expected, that the brightness of the sky, the apparent contrast of the "vessel x" against the sky background, the amount of the "vessel x" exposed in highest contrast and the time permitted for searching were the most important factors in determining how far the "x vessel" could be seen.

Our low-level brightness photometers had not been calibrated by the time we were set to leave for Hawaii. As a result, we were not able to analyse our data in terms of sky brightness as completely as we desired for this report. Graphs are now under study which show to some extent sky brightness and brightness contrast influence on the sighting ranges. Additional data will be collected before conclusions are drawn as to the amount of influence each of these factors has. Before calibrations were made, a graph was drawn which takes the sky brightness into account in a general way, that is in four sectors of the moonlight sky, one for the starlight sky and one for the overcast sky being shown separately. The runs are further separated into similar speeds and distinguishable by color into similar sizes. Accordingly, there is a general comparison of ranges due to 3 levels of illumination, 2 sizes of object and 3 speeds.

The Human Factor

By inspecting the lengths of the lines, one gets an idea of the difference between the first, or farthest sighting, and the last or shortest sighting of each run. The frequent examples of lines unfinished at the bottom, (showing some one or more lookouts did not sight the "vessel x" even at the nearest range to which it approached) shows that motivation and alertness are as essential as any other factor in determining the range to which objects will be sighted regardless of how far they can be sighted.

The investigation proved that under a given light condition, neither the variations in the amount of haze nor the state of the sea nor the speed of a passing ship under observation have

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as much effect upon the ranges of sighting as the variation in the performance of several lookouts during one nights operation or the variation of one man over a period of several nights. On the other hand it proved that each of the above-mentioned factors has some bearing, both on what is seen and how far. The principle factors in seeing an object at sea on a clear starlight night are: physical fitness, including night adaptation; personal motivation; good search procedure; and getting down low enough to silhouette the largest possible area of the object to be seen against the sky. On clear moonlight nights the low point of view holds only when looking toward the moon or within 110° of the moon's azimuth. When searching in the sector from 110° to 180° away from the moon, both high and low lookouts are necessary because, always to observers in aircraft, and frequently to observers on shipboard, the white water around a ship may be seen farther against the background of sea than the ship's structure itself can be seen against the sky. Hence in this case, the high lookout is more important.

Size

On one clear starlight night when a Destroyer could be seen 9,000 yards by observers aboard a "vessel x", the observers on the Destroyer could not see the "vessel x" beyond 2,000 yards. The difference was entirely due in this case to the differences in size of the dark areas silhouetted against the background of the sky. On clear starlight nights observers in aircraft can see the white water that surrounds a moving vessel: the bow wave, the wash along the sides and the wake. In fact, unless an airplane approaches dangerously close, well within 300 yards, white water is all that can be seen. In viewing ships from the air at night, therefore, the speed of the ship is an important factor since its speed and the state of the sea determine to a large degree the size of the white water generated.

Speed of the Vessel "X"

The speed of a "vessel x" when passing or attacking another ship was a direct factor in the range at which it could be sighted. The reason is different for the surface observer than for the aviators and acts the opposite way. For example: When a "vessel x" making 5 kts was attacking a Destroyer the averate range of sighting it was 2,100 yards. But when "x" increased her speed to 15 kts, the average range of sighting decreased to 1,600 yards. Over many attack runs on clear starlight nights at comparative speeds the reduction of sighting range was consistently around 50 yards for each knot of increased speed of the "vessel x" between speeds of 5 and 15 kts. The rate of decrease in sighting range of passing vessels was noticeable but not as markedly so, because the rate

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of approach of the two ships was not the same. The reduction in the average range of sighting attacking vessels was due primarily to the time given to searching a given 60 degrees of the horizon while the range to the vessel was being decreased rapidly as compared to the same time given to search the same size arc while the range to the vessel was being decreased slowly. In other words, when a longer time is permitted for searching any given part of the horizon the chances of sighting are increased and the average sighting range will be greater. The time factor was even more important on moonlight nights.

The fact that the reduction of 500 yards in the average sighting range on attack headings was not offset by the increase in the size of the bow wave and side wash is of more than casual importance.

Greatest Contrast

When the "vessel x" increased her speed she did two things, (a) reduced the time factor and (b) increased the size of her bow wave. However, the size of the bow wave which was appreciably increased was not the part of the area seen in greatest tone contrast by the surface observers and, therefore, the size increase had little or no effect on the net result. This serves as one more illustration that the first perception is dependent on the size of that part of the object only which is in strongest contrast rather than the size of the entire object, part of which is in lesser contrast.

Unfortunately there are insufficient data to determine what the effect of increased speed would be on the range a "vessel x" could be sighted when attacking toward the moon. In this situation the ship is most frequently sighted by her bow-wave and the increase in speed, therefore, should have a greater tendency to offset the time factor.

Importance of Relative Positions of Observing Ship, Vessel X and Moon.

On clear moonlight nights the state of the sea and the direction of search are exceedingly important factors both to observers in aircraft and on board ship. A really smooth sea shoots the range way up as can be seen by a study of the consolidated data sheets. Also it was found that so-called "up moon" and "down moon" are not the logical lines of demarcation between the different areas within which the ranges of sighting differ markedly. The areas divide into four sectors which in this report are called positions and are labeled with Roman numerals. The positions are defined as follows:

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Definition of positions

From the observer's point of view, (observer in the center) when the angle between the moon's azimuth and the true bearing of the ship to be observed is 0° to 20° either positive or negative, the position is I. When the angle is 20° to 110° either positive or negative the position is II. When the angle is 110° to 160° either positive or negative the position is III. When the angle is 160° to 180° either positive or negative theposition is IV. Or in diagrammatic form:

From "vessel x's" point of view, (vessel x in the center) when the angle between the moon's azimuth and the true bearing of the observing ship is 0° - 20° either positive or negative, the position is IV, when the angle is 20° - 70° either positive or negative, the position is III, when the angle is 70° - 160° either positive or negative the position is II, when the angle is 160° - 180° either positive or negative, the position is I. Or in diagrammatic form:

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Size and Angle on the Bow

On all three types of nights investigated, clear moonlight, clear starlight, and totally overcast moon, the amount of "vessel x" presented, that is attitude, or angle on the bow (a.o.b.) made a substantial difference in the range at which she could be sighted. In the tables, diagrams and graphs the attitudes have been divided into two groups, "A" for small a.o.b., and "B" for large a.o.b. Most of the A angles were less than 8° and averaged around 5°. Most of the B angles were over 60° and averaged around 70°.

Brightness and Contrast Measurements

The brightness of the sky, the brightness of the white water when viewed on starlight nights against the sea, the brightness of the sea when seen from the air on moonlight nights and the amount of contrast between these and the dark approaching "vessel x" were always dominant factors. Throughout the investigation, careful photometric measurements were made of the brightness of sky, sea, and a white blotter held vertically. Calculations of the brightness contrasts between "vessel x" and sky have been made but as yet the writer has been unable to evaluate completely the precise numerical relation of the brightness and contrast data to the sighting ranges.

Ships are progressively less visible to an observer, the farther their bearing is from the moon's azimuth because the contrast between the vessel and the sky is progressively reduced. On the other hand, the contrast of the bow wave and wake is generally progressively increased except in the area of the moon reflection on the water. Inside the moon reflection - moon path proper - the wake of a ship disappears when the sea is moderate. When the sea is calm to slight, the wake appears as a dark streak. A wake made on a calm sea in the plane of the moon can be followed for several miles by aircraft flying toward the moon.

Difficulty of Sighting at all from Aircraft

During the investigation, flights were made both in blimps and patrol planes. Both were equipped with good radar and still it was very difficult to find "vessel x" at all. The places of rendezvous were set and we had voice communications as well, but it was generally necessary to request the C.O. of "vessel x" to turn on his search lights to make the initial rendezvous of the evening. Further it was found that on clear starlight nights binoculars were not as reliable as the unaided eye, either from blimp or airplane, even when we had the vessel in our scope and were bombing directly on him. Likewise from shipboard we found that it was very difficult for lookouts to sight the "vessels x" on or even near the

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limits to which they might be seen unless we restricted the field of search. This investigation was not as concerned with the probability of sighting as with the limits to which sightings were possible with given equipment under describable conditions of light and weather.

We found that it was more than six times easier to search 60° of horizon than 360° and in order to obtain reliable and comparable data we used only the 60° of horizon in which we knew the "vessels x" to be. Lookouts and procedures are discussed in another section but it may be mentioned here that in each group of fifteen or more lookouts there was always one who stood out above the others and by as much as 20 or 30% above the average. He did not always sight the "vessel x" first, nor did he always make the farthest sighting in each condition (of illumination, type of atmosphere, etc.). The performance of individuals as searchers has been studied more extensively by other investigators, notably by Luckiesh and Moss of General Electric; Shilling and Verplanck of U. S. Naval Medical Research; and N.D.R.C. under Hardy, Duntley and Blackwell, to name but a few. However, our group did analyze the abilities and performances of our own lookouts sufficiently to determine the variation of each and the relation of each lookout to the group as a whole. By knowing the personal factors to a reasonable extent the other factors of influence were more easily, and we trust, more accurately obtained.

Binocular vs. Unaided Eye

It was obvious that the restricted field of the binoculars and vibration and speed of the aircraft made binoculars liabilities on starlight nights. Our data are not sufficient to draw precise conclusions as to the extent of the liability. However, on clear moonlight nights binoculars were advantageous in the hands of a well-trained observer even in the patrol plane, the speed of which was always at least twice that of the blimp. It should again be pointed out here that in searching the horizon line binoculars covered approximately one-twentieth of the search sector, whereas in searching the sea area required in aerial search, binoculars covered approximately one-ninetieth of the area.

Although again there is insufficient data to make precise comparisons, the ranges of sighting from aircraft flying at 1,000 feet altitude and the ranges of sighting from surface ship appear to be closely alike on clear moonlight nights whereas on starlight nights the surface ship observers have a decided advantage.

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A few of the most important sighting ranges are as follows: On clear starlight nights the average range of 236 sightings through 7 x 50 binoculars was 1,560 yards. The farthest sighting range was 3,600 yards. When binoculars were not used but all other conditions remained the same, the average sighting range was less than 625 yards, the farthest sighting by unaided eye occurring at 1,800 yards. On nights when a moon less than half full was completely overcast, 48 sightings averaged only 1,100 yards using binoculars. The farthest sighting was 1,800 yards. On clear moonlight nights when the moon was more than half full the average range of sighting was 3,540 yards. The farthest sighting was 6,000 yards. These were for attacking attitudes of "x" only.

Procedure

The general procedure during the experiments was as follows: Ten observers were chosen at random from enlisted personnel who had actual lookout experience on one or more of the "vessels x". These men, working in two teams of five men each, were stationed aboard a target-observing vessel at heights of eye between 10 and 38 feet. Each was provided a pair of night "bloomed," Navy issue, 7 x 50 binoculars and carefully assisted in adjusting them to his own eyes. Each was night-adapted with red goggles for ½ hour prior to commencing observation and was cautioned to wear his goggles during periods of relaxation. Normal lookout procedure was followed and stations rotated at random. A sweep rate of one degree per second was used. Sightings were reported directly by the lookout via a self-powered telephone set to a lighted control room where records were made. As a lookout swept his assigned sector he reported all objects, their relative bearings, and the time at which he finished each sweep. The lookout was informed in advance that an object would appear in his search sector, and he knew it would be the "vessel x" or a persistant "white water" and that it would probably first appear as a blur or vague "dark bump" on or a depression in the horizon. The time of sighting of the test object was noted by means of a stop watch. This time was then later converted into range by referring to radar range records, taken both by the "vessel x" and also by the DD every thirty seconds throughout the maneuver. These were again checked by graphic plots of each run. All data sheets were scored by the officer-in-charge of the project and the sure sighting ranges were obtained by comparing the reported bearing with the actual, and by evaluating the lookout's statements of certainty and his description of the object seen.

Photometric measurements of the brightness of the sky and sea near the horizon together with recordings of the weather conditions, state of the sea, temperature, relative humidity, barometric pressure and atmospheric visibility were made by trained aerologists concurrently with the sighting data.

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CONSOLIDATED RANGE DATA

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CONSOLIDATED RANGE DATA

Conditions of Experiment	5 KNOTS Vessel "x": No. of sightings	5 KNOTS Vessel "x": Range Aver. (in hundreds of yards)	5 KNOTS Vessel "x": Range Maxim. (in hundreds of yards)	10 KNOTS Vessel "x": No. of sightings	10 KNOTS Vessel "x": Range Aver. (in hundreds of yards)	10 KNOTS Vessel "x": Range Maxim. (in hundreds of yards)	16 KNOTS Vessel "x": No. of sightings	16 KNOTS Vessel "x": Range Aver. (in hundreds of yards)	16 KNOTS Vessel "x": Range Maxim. (in hundreds of yards)	Total No. of sightings	Range Aver. (in hundreds of yards)	Range Maxim. (in hundreds of yards)
Starlight Nights--A*	50	20.4	31.0	95	15.1	36.0	91	13.8	27.0	236	15.6	36.0
B*	30	26.8	43.0	26	36.0	45.0	30	23.3	36.0	86	26.1	45.0
Combined A & B	80	22.5	43.0	121	17.8	45.0	121	16.2	36.0	322	18.4	45.0
Overcast Nights--A	16	13.4	18.0	16	8.0	17.5	16	11.8	18.0	48	11.1	18.1
B	12	16.4	24.0	12	17.0	24.0	8	16.0	21.0	32	16.6	24.1
Combined A & B	28	14.7	24.0	28	11.9	24.0	24	13.2	21.0	80	13.1	24.0
Moonlight Nights--IA	-	-	-	-	-	-	5	31.6	40.4	5	31.6	40.4
IIA	-	-	-	-	-	-	30	40.2	60.0	30	40.2	60.0
IIIA	-	-	-	5	19.2	22.8	29	35.4	58.0	34	32.7	58.0
IVA	-	-	-	-	-	-	30	34.1	52.0	30	34.1	52.0
Combined A	-	-	-	5	19.2	22.8	94	36.2	60.0	99	35.4	60.0

IB	-	-	-	-	-	-	-	-	-	-	-	-
IIB	8	86.8	129.0	20	80.0	102.0	25	67.5	79.0	53	75.2	128
IIIB	13	69.4	92.0	37	71.5	104.0	41	42.8	71.0	91	58.6	104.
IVB	-	-	-	20	64.5	99.0	15	45.8	67.0	35	56.4	99.
Combined B	21	76.2	128.0	77	71.8	104.0	81	51.0	79.0	179	62.9	128.
Combined A & B	21	76.2	128.0	82	68.6	104.0	175	43.1	79.0	278	53.2	128.
Summary	129	29.6	128.0	231	35.2	104.0	320	30.7	79.0	680	32.0	128.

Summary

Small angle on the bow; all light conditions & positions, sighting from ship	383	20.2	60.0
Large angle on the bow; all light conditions & positions, sighting from ship	297	47.3	128.0
All sightings from Aircraft on Clear Moonlight Nights	6	81.0	136.0
All sightings from aircraft and blimp on clear starlight nights	22	12.0	58.0
All 708 sightings shown in this table, from ship, airplane, and blimp	708	32.0	136.0

*A = Small angle on the bow
*B = Large angle on the bow

Four basic maneuvers were used to bring "vessel x" across the threshold toward the observing ship. (1) "Vessel x" passed the observing ship on a reciprocal course. This maneuver was later discarded as it caused rapid changes in the angle on the bow of the "vessel x" and also necessitated shifting the search sector at frequent intervals. (2) The observing ship gradually closed on "x" which was on a nearly parallel course so that a constant broadside view was always presented to the observers. (3) "Vessel x" made attack or "minimum silhouette" runs on the observing ship which was either lying-to or maintaining a constant course. At the beginning of each of these maneuvers "x" was beyond the visual threshold and was gradually brought closer until each observer had a chance to "sight" it. The speed of "vessel x" was held constant on each run, but was varied from 5 to 10 to 15 knots on different runs in an effort to determine the best speed of attack and of a skirting or passing course. A fourth maneuver was used when observations were made from aircraft. The "vessel x" took a straight track at constant speed for 30 minutes, changing speed or course, or both at the end of this interval. On moonlight nights tracks were laid out at varying angles with respect to the moon, both for surface and aerial observations. A blimp or a PBY patrol plane approached "vessel x" a number of times during each 30 minutes period from a variety of directions. The course and speed of "vessel x" and of the observing craft were plotted.

<u>Recommendations</u>

Even though this investigation brought out some new and useful information, we could not always be sure of the reason <u>why</u> certain things happened nor of the precise amount of the influence each factor contributed. This was due partly to the need for more field data and partly to the need for additional basic information in the science of seeing. A considerable amount of basic material has been recently acquired by other agencies but so recently, there is still a gap between these new facts and the means for applying them to practical problems. For example, it is known that when certain light and weather conditions exist, it follows that an object of a given size, shape and reflectance can be seen a certain distance. But the conditions and objects, though familiar and qualitatively describable, have not been measured and classified into a usable form, and, in some cases, have not been measured at all. Another example: Though it is known how far a circular disk can be seen, it is not known how far a complex form like a ship can be seen.

Some needed instruments, the design and function of which are clearly indicated, have never been built whereas other instruments such as the O'Brian-Taylor low level photometer are lacking in sufficient quantities to permit general distribution.

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1. A considerable amount of original research, both basic and applied, has been conducted on vision, visibility and optical aides by various independent groups during the past four years, particularly in the United States and Great Britain.

Accordingly, it is recommended that copies and compilations of reports of all vision and visibility wartime researches be reviewed by ORI, C.N.O., or a committee appointed by one of them, and the usable results be published in a compendium.

2. When Naval personnel become familiar with the various moods of sky and sea, day and night, can describe objects on the horizon in terms of light or dark, sharp or soft and so on, their efficiency as lookouts increases surprisingly.

Accordingly, it is recommended that a text book on "The Fundamental Principles of Observing" be prepared for required reading of all Naval personnel.

3. In order to gain additional information which applies directly to "x vessel" concealment and to gain additional basic information on vision and concealment of objects which will be comparable to data contained in this report, it is desirable that the same test object be used.

Accordingly, it is recommended that the investigation to determine the visibility of "vessels x" under various light and weather conditions be continued.

4. It is believed that the observations of lookouts at sea as here reported and the performance of observers working under controlled laboratory conditions, furnish a means of determining a relationship between the two. It this relationship can be measured within reasonable limits, performance at sea can be forecast and field research reduced to a minimum.

Accordingly, it is recommended that an investigation be conducted to determine relationships between, "The Perceptual Capacity of the Human Observer" and "Visibility of Naval Targets", two late reports by Professor S. Q. Duntley, and the performance of lookouts at sea as reported in this paper.

5. It is recommended that the investigation of the use of binoculars and other optical instruments at sea be continued.

6. It is recommended that an investigation be conducted to determine the most effective method of visual search for Military and Naval targets against land, sea, and sky backgrounds.

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7. It is recommended that an investigation be conducted to determine the visibility of wires, pilons and other obstructions commonly on or in the vicinity of aircraft landing fields.

8. There are individual groups within the Army and Navy engaged in vision and visibility research and/or in the testing and/or reshaping into practical form for Military or Naval use, material on vision and visibility.

It is recommended that these groups be directed to continue so long as the particular investigationsor tests in which they are engaged relate primarily or exclusively to Naval or Military problems.

9. It is recommended that an investigation be conducted to establish the relationship between the visibility of common objects (or objects of Military or Naval significance) and the fundamental functions of illumination, brightness contrast, size, shape, color and atmospheric attenuation, and also in terms of the more commonly recognizable variables such as sea and sky brightness, wind force and direction, cloud cover, barometric pressure, relative humidity, temperature, type and level of illumination, etc.

10. The visibility of any object depends to a large degree upon certain characteristics of the particular object: Size, shape and reflectance. Reflectance is generally the factor about which least is known. This deficiency can be easily made up and will greatly assist in the calculation of the visibilities of these objects including harbors, buoys, ships, airstrips, etc.

Accordingly, it is recommended that an investigation be conducted to measure and/or tabulate the illumination and reflection properties of lights and common objects respectively, which have direct bearing on Navigation and Naval Aviation.

11. It is recommended that the Navy file a formal request with the U. S. Weather Bureau for a new definition of visibility based upon the ability of average observers to perceive common objects of definite size in the day time and common lights of definite candle power at night.

12. It is recommended that a project be established to develop a contrast meter calibrated to read in percent, and low level brightness photometers be given wide distribution.

13. The investigation of vision and visibility as applied to aviation, navigation and other Army and Navy practices requires frequent aerial flights and long range observations at sea and ashore. Good weather, access to ships and aircraft are highly desirable assets, and in many instances

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essential to successful visibility investigation. For these reasons, and because it is believed that a <u>headquarters</u> should be established for directing Naval visibility <u>field</u> research and testing, it is recommended that a small organization be established under CNO or the Operational Development Force, with headquarters at Point Loma, California.

14. In a letter to ORI via BuAer and CNO, it has already been proposed that steps be taken by ORI for the coordination and integration of vision and visibility research. It is believed that the action already taken on this proposal, and favorable action which it is hoped will be taken on the other recommendations here made, will lead to a better understanding of the science of seeing.

Discussion:

Because of the shortage of time, informal discussions of this paper were carried on during the luncheon recess. Comdr. Brown exhibited sketches which he had prepared to simulate the appearance of targets at the visual threshold.

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DIGEST OF DISCUSSION CONCERNING RESEARCH PLANS IN VISION

The Chairman called for a discussion of long-range research plans in the field of vision. Because of the large amount of material for discussion, the group primarily interested in vision testing withdrew to discuss the AGO research program and formulate recommendations to the entire Committee. The Chairman retired to preside over the visual testing meeting, and the Secretary assumed the Chair for the remainder of the meeting.

The Chairman called for reports from the military activities represented of their research needs and facilities available in the field of vision.

Army Air Force: Capt. Chapanis reported that the AAF is concerned with problems of visual performance at high altitudes and high speeds. Under these conditions, pilots are no longer searching for targets; the activities of targets and of their own plane are indicated by radar.

The Chairman asked whether vision research is being conducted at Wright Field.

Capt. Chapanis replied that development of sun-goggles and eye protective equipment is being continued. Investigations of visibility from aircraft, with special reference to the optical quality of transparent sections, are being made. In addition, interest is present in problems of night vision, design of instrument dials, lighting of aircraft, and problems relating to the nature of radar presentations.

Army Ordnance: Mr. John Darr reported that his office was interested in visual factors which affect design of optical instruments for search. The research of Army Ordnance is concerned with developing individual instruments rather than with investigating general problems. Since there are no research laboratories connected with Army Ordnance, research reported before the Vision Committee often supplies the desired information.

Adjutant General's Office: Since the representatives of this office had withdrawn to the meeting on acuity testing, the Chairman reported for them. This organization is at present concerned primarily with testing visual acuity and night vision.

Quartermaster: Mr. Dokken reported that the interests of the Quartermaster are similar to those of Ordnance. QM is also without direct research facilities and does not at present support any research programs. Interest is present in the testing and development of goggles, especially anti-fogging.

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The Chairman inquired whether problems had arisen which demanded research beyond the facilities of the Quartermaster.

Mr. Dokken replied that the optimum density of sun-goggles and the use of polarizing materials for sun-scanning constituted such problems.

Surgeon General: Col. Randolph reported that his office is concerned with ocular protection from injury and with visual testing in connection with recruiting and classification.

AGF: Col. Alexander reported that the interests of his group are similar to those of Army Ordnance and Army Quartermaster. He emphasized the need for more rugged instruments, more effective means for reading scale markings and methods for reducing vibration. He reported that a general consideration of the problems involved in rifle sights was needed.

Marine Corp: Major Sherrill stated that in addition to the general problems expressed by Col. Alexander, the Marine Corp is interested in procuring a small portable rangefinder.

Dr. Graham commented that it is probably impossible to construct a satisfactory portable rangefinder because of the complex nature of individual differences in depth perception. Correction devices are always required to compensate for these differences, which probably could not be incorporated into such an instrument.

Navy, BuAer: Lt. Comdr. London reported that the problems of BuAer paralleled those of Army Air Forces. In addition to visual problems concerned with high altitude and high speed, problems of instrument lighting and interior and exterior lighting of aircraft have been considered. Additional problems were reported by Lt. Comdr. H. H. Stuart, who mentioned rescue equipment, signal equipment, and self-contained transmissometers.

The Chairman asked whether BuAer has any established research projects.

Lt. Comdr. Stuart replied that Air Station facilities were being employed for limited research.

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2. Needs: Permanent research personnel.

3. Facilities: (a) Physiology: Human centrifuge, special Link trainer and one airplane available for study of influence of non-auditory labyrinth upon visual perception.

   (b) Psychology: Three special dark rooms, NDRC adaptometers (Models II and III), MacBeth illuminometer, and complete night vision training equipment for study of visual perception at low intensities of illumination.

   (c) Ophthalmology: Two complete vision testing rooms, and subjects from (1) the Eye Clinic, (2) the Aviation Examining Room, and (3) Flight and Cadet groups. Adequate facilities for both laboratory and clinical investigations of visual acuity, refractive errors, motor anomalies, peripheral vision and depth perception.

BuMed: Capt. Korb emphasized that BuMed needs validated visual standards, both for day and for night duty.

BuOrd: Lt. Comdr. Pulling reported that BuOrd is concerned with the design of new instruments and the proper use of existing equipment for primary recognition of targets, spotting of gunfire, and direction of guns. The correlation of laboratory and field data is a necessary step in this program.

The Chairman asked whether facilities were available for such proposed research.

Lt. Comdr. Pulling reported that BuOrd has no laboratories and at present has only a single pertinent contract with Pennsylvania State College. BuOrd can make use of Naval Gun Factory for testing optical instruments.

CNO: Comdr. Volk outlined the responsibilities of CNO as the executive branch of the Navy. Facilities are not available for research, nor is research the primary interest of CNO. In conjunction with the maintenance of peak efficiency in the Fleet, CNO may direct certain bureaus to engage upon research programs. Comdr. Volk emphasized the necessity for adequate coordination and liaison between the various research groups.

Dr. Lamar reported the plans of the Operations Evaluation Group, CNO. This group is concerned with evaluating operational data in order to give advice on tactics and strategy. Dr. Lamar emphasized the need for information concerning the probability of detection of a target as a function of its location, size,

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brightness, and exposure for various field brightnesses. Preliminary data of this sort have been obtained during the war, but have usually been restricted both in the location of the target (with respect to the direct line of sight) and in the duration of exposure of the target. Certain theoretical principles have been developed which should be tested by laboratory experiment. Laboratory data should then be correlated with actual data obtained with various scanning procedures.

The Chairman requested information concerning the facilities of the Operations Evaluation Group.

Dr. Lamar reported that there are no research facilities under OEG. A competent staff is available for liaison and to give advice on scientific problems. The operational data of the past war are available to this group and in general are reduced to tabular form.

BuPers: Lt. Snidecor reported that this bureau is concerned with personnel factors contributing to effective day and night vision. It was emphasized that almost nothing is known about the factors of learning in visual perception. A great deal of effort has been expended in lookout and recognition training, but the fundamental principles have not been investigated. Lt. Snidecor emphasized the advisability of sending all information which might be useful for practical instructional purposes to BuPers, no matter how simple the information seemed.

BuShips: Capt. Bittinger requested development of a variable-magnification optical instrument for use in all kinds of visual search. Discussion of this matter by Lt. Comdr. Pulling and Capt. Bittinger revealed that in the past the advantages have not justified the expense.

Comdr. Brown described his proposed manual of instructions for observing. This handbook is intended to teach Naval personnel the principles involved in observing by picturing for them the appearance of targets at or near the visual threshold.

NRL: Dr. Tousey described the organization of NRL and indicated visual problems with which the Laboratory is primarily concerned. Plans are being made to continue the development of transmissometers, photometers and intermittent signaling devices. NRL is interested in the visual factors pertinent to the performance of optical instruments. In this connection, data on the visibility of targets are needed.

NMRI: Lt. (jg) J. E. Birren reported that this activity will be concerned with vision only in terms of the human factors in instrument design.

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MFRL, Camp Lejeune: Ensign Mueller stated that Camp Lejeune has conducted research in the past for the Navy and the Marine Corp, including miscellaneous studies in vision. He emphasized that the available facilities are limited.

David Taylor Model Basin: Dr. Windenberg reported that David Taylor Model Basin is interested in instrument design. The difficulties inherent in field tests suggest the advisability of a facility to provide an intermediary step between laboratory and field conditions. A model of such a facility (known as a small-scale Visibility Theatre) is now located at the Model Basin.

ORI: Comdr. Liddel described the mechanism for establishing research contracts between civilian laboratories and ORI.

The Chairman summarized the discussion of facilities and research needs in the armed forces. He reported that, prior to the meeting, the Vision Committee staff had accumulated suggestions for research needs and information about civilian laboratory facilities. He requested that a digest of the information compiled in this way be incorporated into the Proceedings of the meeting.

Research Needs in the Field of Vision

The general fields of investigation considered as proper subjects for vision research are presented in outline form:

A. PHYSIOLOGY AND PSYCHOLOGY

- I. General, textbooks
- II. Visual acuity and contrast sensitivity
- III. Visibility as a function of wavelength
- IV. Color vision
- V. Night vision
- VI. Visual fields
- VII. Flicker and summation effects
- VIII. Distance (depth, stereoscopic vision)
- IX. Ocular dominance and binocular phenomena
- X. Perceptual phenomena
- XI. Motion perception
- XII. Autokinetic and similar phenomena
- XIII. Neurophysiology
- XIV. Vitamins and diet (vitamin therapy)
- XV. Metabolic factors (anoxia, blood sugar, carbon dioxide, and hyperventilation)
- XVI. Drugs and other factors
- XVII. Visual fatigue, eyestrain (asthenopia)
- XVIII. Peripheral muscular mechanisms
- XIX. Intra-ocular tension; glaucoma
- XX. Visual illusions

B. VISUAL EXAMINATION AND TESTING (INCLUDING METHODS AND INSTRUMENTS)

I. Testing methods
II. Induction and employment standards
III. Examination of inductees and military personnel
IV. Refractive errors
V. Acuity
VI. Color vision
VII. Depth perception
VIII. Night vision testing
IX. Accommodation
X. Muscle balance
XI. Interpupillary distance
XII. Selection for military specialties
   (a) Stereoscopic height finders and rangefinders
   (b) Aircrew
   (c) Radar operators
XIII. Malingering and neuroses
XIV. Special instruments
XV. Aniseikonia

C. CORRECTION OF OCULAR DEFECTS IN MILITARY PERSONNEL

I. General ophthalmology
II. Dioptric correction
   (a) Glasses
   (b) Goggles
   (c) Contact lenses
III. Corrective training
   (a) General
   (b) Acuity
   (c) Phorias
   (d) Color vision

D. TRAINING FOR MILITARY SPECIALTIES (INCLUDING OPTIMAL CONDITIONS AND PROCEDURES, JOB ANALYSES)

I. Recognition
II. Visual search
   (a) Night lookout
   (b) Air-sea search
   (c) Naval lookout
   (d) Ground patrol (including night firing)
   (e) Night flying
III. Specialized duties
   (a) Rangefinding
   (b) Radar (and C.I.C.) operation
   (c) Other fire control
   (d) Pilot

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E. OCULAR TRAUMA (IN MILITARY SERVICES)

I. Mechanical injuries (incidence and types)
II. Chemical (gases, drugs)
III. Burns (flash, general)
IV. Arc welding
V. Solar radiation
VI. Radar operation
VII. Detached retina
VIII. High and low pressure, blast
IX. Localization and diagnosis
X. Surgical treatment
  (a) General
  (b) Removal of foreign bodies
  (c) Plastic surgery
  (d) Keratoplasty
  (e) Prosthesis
  (f) Enucleation
  (g) Detached retina
XI. Conjunctivitis
XII. Infections
XIII. Medical treatment
  (a) General measures (drugs, physiotherapy, etc.)
  (b) Sulfa drugs
  (c) Penicillin
XIV. Trachoma
XV. Rehabilitation
XVI. Blindness

F. GOGGLES AND OCULAR PROTECTION

I. General purpose (sun, wind, dust)
II. Dark adaptation
III. Structural design
  (a) Fogging and frosting
  (b) Visual field restriction
IV. Helmets, face masks, visors
V. Industrial protection
VI. Gas protection
VII. Sun-scanning
VIII. Filter combinations simulating night vision
IX. Special visual aids
  (a) Tracer
  (b) Submarine targets
  (c) Horizon
  (d) Camouflage
  (e) Anti-searchlight

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G. ILLUMINATION

I. Sources and materials
  (a) General
  (b) Luminescent
II. Interior illumination
  (a) General
  (b) Cockpit
  (c) Ship
  (d) Submarine
  (e) Armored vehicles
  (f) Radar and other installations
  (g) Maps and charts
III. Instruments and dials
IV. Dazzle
V. Factories
VI. Airports

H. VISIBILITY AND SPECIAL PROBLEMS

I. Visibility of targets under natural illumination
II. Legibility
  (a) Dials and controls
  (b) Radar presentations
  (c) Printed markers
III. Blackout (including exhaust)
IV. Obscuration by smoke
V. Camouflage
  (a) General (materials, paints)
  (b) Ground
  (c) Ships
  (d) Aircraft
VI. Visual signals
  (a) Light
  (b) General
  (c) Ultraviolet and infra-red
  (d) Retroreflective
VII. Transparent sections
VIII. Vision from enclosures
  (a) Tanks
  (b) Aircraft
  (c) Director control towers
IX. Gun flash
X. Searchlights
XI. Gunfire spotting

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J. MILITARY USE AND DESIGN OF OPTICAL INSTRUMENTS AND AIDS TO VISION

I. Fire control instruments
   (a) Gun sights (directors, trackers)
   (b) Night gun sights
   (c) Reticles
II. Rangefinders
III. Viewing devices (binoculars, telescopes, periscopes)
IV. Special scanning devices
V. Optical engineering; materials and methods

Correspondence with Vision Committee members revealed that the most immediate research need is summary technical reports of the research conducted during the war years.

Specific suggestions for research needs are presented below, designated with reference to the outline of research topics above:

A -- II. Medical Research Laboratory, New London, reports the need for a study of visual acuity as a function of visual distance. It also reports the need for a continuation of the study by Dr. F. D. Burger to determine variations in visual acuity at low illumination levels.

IV. Medical Research Laboratory, New London, reports the need for a study of the nature of photoreception, especially for chromatic objects. In addition, a study of foveal and para-foveal color vision (including macular pigmentation) should be undertaken.

V. Dr. Hartline indicates the need for investigating the rate and extent of dark adaptation during the initial few seconds.

VIII. Medical Research Laboratory, New London, emphasizes the need for fundamental research in depth discrimination.

XV. Medical Research Laboratory, New London, mentions the necessity for information concerning the effect of reduced oxygen tension on scotopic perimetry and scotometry. These studies, it is believed, will reveal most effectively the effects of oxygen on rod function.

B -- VI. Medical Research Laboratory, New London, considers there to be need of a color vision test to evaluate the degree and type of color deficiency, with adequate standardization.

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VIII. Medical Research Laboratory, New London, suggests that the use of autokinetic neptagmus as an objective test for scotopic perception be investigated.

C -- III.

a. Medical Research Laboratory, New London, considers there is need for a thorough and unbiased study of orthoptics and alleged treatments of myopia.

d. Navy (BuMed) suggested that the Dvorine method of corrective retraining of color blindness be investigated.

E -- XVII. Medical Research Laboratory, New London, reports the need for a thorough investigation of visual fatigue.

F -- I. Army (Quartermaster General) requests answers to the following questions:

a. Exactly what minimum density of sunglass is required to preserve subsequent dark adaptation?

b. At what maximum density does the protection fail to yield profit?

c. What is the proportional effect of the inclusion of polarizing material in the sunglasses?

d. What is the maximum amount of color which is permissible before prejudice to color vision?

e. If an amount of color is permissible, what color is preferable?

H -- I. The Operations Evaluation Group, CNO, has submitted the following problems:

(1) To find the probability of detecting a target in a given length of time as a function of its apparent size, shape, and contrast, the illumination, and the size of the field of view.

(2) To find the time required to identify a target at a known position as a function of its apparent size, shape, and contrast, and the illumination.

(3) To find the accuracy with which a given sight can be set on a given target as a function of the type of sight, the target size, shape and contrast, the illumination, and the motion of the target.

(4) To find the effect of the atmosphere on the apparent contrast and illumination of targets.

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Comdr. Dayton R. E. Brown, BuShips, has submitted the following recommendations:

1. A text book based on our experience to date, on "The Fundamental Principles of Observing" be prepared for required reading of all Naval Midshipmen and students and instructors in lookout schools. This book can be enlarged and amended after further researches in vision and visibility have progressed.

2. An investigation be made to establish means for determining the "visibility" (as defined by the meteorologists) more completely and in terms of the likely perception of one of a number of common objects day or night rather than in terms of the recognition of a large dark object in daylight only.

3. An investigation be made to establish the relationship between the visibility of common objects (or objects of military or Naval significance) and the fundamental functions of illumination, brightness contrast, size, shape, color, and atmospheric attenuation.

4. An investigation be made which will permit the qualitative and quantitative analysis of the visibility of atolls, landing fields, ships, aircraft, lighthouses, navigating lights, test objects of given size, etc., in terms of the fundamental functions wherever possible, and also in terms of the more commonly available contributing variables such as sea and sky brightness, wind force and direction, cloud cover, barometric pressure, relative humidity, temperature, type and level of illumination, etc.

5. An investigation be made to determine the illumination and reflection properties of lights and common objects respectively which have direct bearing on Navigation.

6. An investigation be made to determine the visibility of wires, pilons and other obstructions commonly on or in the vicinity of aircraft landing fields.

The U. S. Weather Bureau, currently engaged in a Visibility Projects Survey, has submitted a statement of needs in visibility research, prepared by L. P. Harrison and H. H. Neuberger:

The statements represent the result of a preliminary survey of recent and past visibility research and do not claim completeness. Also, some of the phases may have been investigated but not yet come to the attention of the writers.

The problems presented stem largely from the requirements of military and commercial traffic in the air, at sea, and on land for visibility observations and forecasts.

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All of the past theoretical work was based on idealized conditions and simplification of some of the physical processes involved and omission of others. Experimental work was performed either in the laboratory or in the field under selected conditions. Generalization of results obtained under special conditions or the application of laboratory results to field problems is not necessarily valid without further research especially in view of the fact that no criterion is available for recognition of the existence or non-existence of "ideal" conditions in the field.

The need for research in theory, and in objective as well as standardized subjective field methods of measuring and observing visual range is outlined as follows:

A. Horizontal visual range in daytime, when

1) the target is black, white, or colored (with various degrees of reflectivity)

2) target is viewed against various types of terrestrial background

3) no natural targets are available or there is insufficient choice of such targets as on board ship, on small islands, or in flat isolated country

4) target is not of simple geometrical shape

5) subtended angle of target has a value from a small fraction of a degree to the maximum likely to be used

6) various conditions of sky cover exist especially with non-uniform clouds, or thin overcast; also clear sky with non-black targets

7) underlying terrestrial surface is not a uniform diffusely reflecting surface (land and sea)

8) sun is at various azimuths with line of sight

9) horizon sky begins at various angles of elevation above the top of the target

10) line of sight is inclined by a small angle

11) dense fog, haze, smoke or dust prevails

12) precipitation (rain, snow, etc.) is falling

13) airlight is cut off, in part, by large objects (mountains)

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B. Analogous problems for night time horizontal visual range, including

a) instruments for measuring visibility

b) the use of various types of reflectors as targets at isolated stations or on small islands

c) floating light sources (temporary or permanent) for use on board ships or on small islands

C. Slant visibility and horizontal visibility aloft

1) balloon-carried instruments for measuring visibility conditions aloft

2) possible use of ceilometers to measure vertical distribution of attenuation coefficient

3) translation of horizontal into oblique visibility under various conditions

4) balloon-carried targets for observing slant visibility

5) relation of various meteorological elements to illumination at the surface

D. Standardization of observing procedures

1) adoption of target standard in respect to angular size, shapes, reflectivity and color, candle power, distance

2) reduction of data derived from non-standard targets

3) use of reflectors with transmissometer to eliminate lengthy cables and possibly increase base length

4) determination of conversion factors for various atmospheric conditions which will translate transmissometer measurements into visual range

5) application of physiological optics to observing problem (light and dark adaptation etc.) and selection of meteorological observers.

E. General Problems

1) the validity of Koschmieder-Löhle airlight formula and its limitations. (the question of attenuation coefficient as a function of target distance in day time and at night)

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2) applicability of threshold values obtained in laboratory to various conditions in the field

3) micro-physics of the atmosphere (the relationship between optical properties of the atmosphere and other physical properties such as suspensoids, turbulence, etc.)

4) spectral properties of attenuation in the atmosphere and its application to signalling, lighting, goggle vision etc., especially under conditions of fog and haze

5) possible development of laboratory method simulating earth, atmosphere, and sun, in which the various optically effective factors (such as illumination, precipitation, etc.) can be variably controlled. ("Equivalent solar-terrestrial-atmospheric optical system" in which dimensional similitude conditions must be satisfied)

6) the forecasting of visibility in synoptic practice

J -- III. Operations Evaluation Group, CNO, report need for information concerning the effect of optical systems on the apparent size, contrast and illumination of targets.

The group which had withdrawn to consider the AGO research program returned its report:

Discussion by various members of the Army-Navy-NRC Vision Committee revealed substantial agreement with the proposed design for the AGO experimental program. Specific issues discussed, and decisions reached are listed:

a. The list of test charts was considered satisfactory with one additional test chart being recommended for inclusion in the experimental battery. This test chart presumably measures vernier acuity. The figure in the chart is a cross with one of the four lines in the cross split and offset a slight amount at half its distance from the center of the cross.

b. All were in agreement that no single scoring procedure should be followed without investigation of its merits and that several types of scoring procedures should be studied.

c. The practice problem for training subjects to guess was considered satisfactory.

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d. Lt. Comdr. Dean Farnsworth was the only member of the group who had any serious objections to handing the subject a familiarization chart before each test. It was recommended that a trial run using such familiarization charts be undertaken at New London before making the final decision on how these familiarization charts should be presented.

e. It was agreed that the floor coloring should be a darker color than the rest of the test booth to compensate for greater incident illumination.

f. After considerable discussion, it was agreed that all testing should be done with the left eye. Arguments for the dominant eye or the right eye were counteracted with the opinion that a wider range of scores would be obtained on the left eye. It was also agreed that it would be desirable either to eliminate all men who habitually wear glasses or to identify them clearly and record the length of time that the glasses had been removed prior to testing.

g. On the basis of distribution of test scores on Snellen, New London, and other charts reported earlier in the meeting in the study, "Visual Acuity Measurements with Three Commercial Screening Devices", questions were raised as to the range of the items in the various test charts. It was agreed that the lower limit on the test charts should be at least one logarithmic step below 20/10, namely, 20/8.4 (a figure of 0.02933 inches at 20 ft., a minimum visual angle 0.421), and it was also agreed that if possible, the upper limits should exceed 20/40.

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DIGEST OF DISCUSSION CONCERNING
FUTURE ACTIVITIES OF THE COMMITTEE

The Chairman called for a discussion of desirable future activities for the Committee:

Various members emphasized the necessity that the Committee, or some other agency, provide effective liaison between civilian scientists and military officers.

(1) It was proposed that permanent line officers of the Army and Navy be invited to appear at a subsequent meeting of the Committee, to discuss the research needs in the field of vision in the light of their recent combat experiences.

(2) It was reported that civilian scientists could gain access to military installations through their appointment as consultants to one of the several military agencies. This mechanism has been established as a part of the present organization of the Committee.

It was proposed that the Committee act as temporary custodian of war-surplus experimental equipment, to be made available to civilian laboratories or military installations.

VOTED: That a subcommittee be appointed to establish means whereby equipment for visual research can be received, stored and made available on loan for use by various laboratories, civilian and military.

Subsequently, the following committee was appointed:

Comdr. Urner Liddel, Chairman
Lt. Comdr. Nathan H. Pulling
Dr. Detlev W. Bronk
Mr. John E. Darr

The Chairman asked the Committee its wishes regarding number of meetings. A show of hands indicated that the membership desired the Committee to schedule three additional meetings during the calendar year. Discussion indicated the advisability of holding at least one meeting at which small working groups could discuss technical issues.

The Chairman requested assistance from the membership in adding persons both qualified and interested to the representation at the meetings. Suggestions were received which included: U.S. Weather Bureau; Army Signal Corp; Weather Division of Army; G-4, Army; Ships Characteristic Board; G-1, Army and New Developments Division, Army Staff.

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Comdr. Brown requested that the Vision Committee consider recommending to the Navy that a field headquarters for vision research be established at Point Loma, California.

The membership of the Committee agreed in general to the need for new facilities for vision research, but did not wish to make a definite recommendation without careful study. Accordingly, it was recommended by the Chairman that Comdr. Brown's suggestion be tabled.

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ABSTRACTS OF CURRENT LITERATURE

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ABSTRACT

128. Cathode Ray Tube Screens for Daylight and for Night Viewing.

Gt. Brit. Research Laboratories of the General Electric Co., Ltd. R. G. Hopkinson. Report No. 8713, Ref. No. 1R19, 21 Aug 1945 (R)

Various luminescent materials were tested in order to perfect a C.R.T. screen which could be used both for day and night viewing. In the day, maximum luminous efficiency is desired. At night, a distribution of energy is required which will permit maximum clarity of foveal vision without disturbing the level of adaptation of the peripheral retina.

Tests were made on various phosphors to determine the luminous efficiency in day viewing. With the addition of a red filter, computations were made to determine the amount of foveal excitation relative to peripheral excitation for each of the materials tested. Under these circumstances, the most satisfactory material (including willemite) was a sulphide powder, 0132A8, which is a form of ZnS.Cds:Cu.

In the United States, N.R.L. and the Johnson Foundation have used a willemite screen, with an orange filter for modifying the spectral quality of emission in order to provide maximum efficiency in night viewing. When willemite is used under these conditions, its over-all efficiency for low accelerator voltages is equivalent to that of 0132A8 in conjunction with a red filter. In voltages greater than 2 KV, however, willemite and an orange filter are not as efficient as 0132A8 and a red filter.

129. Threshold and Signalling Ranges of Point Sources of Light in Fields of Brightness from Dark to Daylight. Knoll, H. A.; Beard, D. S.; Tousey, R; and E. O. Hulburt. Naval Research Laboratory Report H-2627; 11 October 1945, 20 pp. Open

The threshold illumination at the eye for a steady source of light subtending 1.0 minute of arc was measured for fields of brightness surrounding the source varying from complete darkness to bright daylight. Observations were binocular, and the five observers were allowed to fixate where they chose. The threshold was defined as the illumination at which the source was always just visible.

A 20° uniform field surrounded the source; experimentation showed that threshold illumination was not noticeably changed when the diameter of the field was reduced from 20° to 0.8°. It was demonstrated that threshold illumination was not changed if the uniform field were replaced by a bipartite field, one portion of which was dark, and if the source varied in distance from the nearest portion of the boundary line from 5° to 0.4°.

A mathematical treatment of the effect of the atmosphere upon illumination from a point source of white light is presented. The threshold illumination data are combined with appropriate atmospheric attenuation factors in the form of a range nomograph. This nomograph permits the computation of the threshold range from source candlepower, sky brightness, and condition of the atmosphere. Ranges computed in this way were found to be in agreement with Naval experiments at sea.

The conversion of threshold candlepower into candlepower adequate for signalling purposes can be accomplished by application of a factor varying between 30x and 150x.

130. Comparison of Various Screening Devices with Standard Medical Visual Procedure. Sulzman, John H; Farnsworth, Dean; Cook, Ellsworth, B; Bartlett, Neil R; and Mary I. Kindred. Progress Report No. 1 on BuMed Project No. x-493 (Av-263-p) Medical Research Department, U. S. SubBase, New London, 49 pp. Open.

A preliminary statement is made of the research program undertaken at New London to compare the performance of three commercial visual screening devices with standard visual testing procedures. The three screening devices were: Bausch and Lomb Ortho-Rater, Keystone Ophthalmic Telebinocular, and American Optical Visual Screening Device. The data of this report are concerned primarily with the Ortho-Rater.

"It was evident at the outset of this study that clinical visual testing procedures were not sufficiently standardized to permit comparisons of the performance of devices constructed as screening tests for clinical examinations.

"Accordingly, visual examination procedures were defined. First, the conditions of testing were stipulated and controlled; these involved: (a) some control over the physical condition of the observers to be tested; (b) specificity of the testing procedure; (c) test-target illumination; and (d) test-targets. And second, acuity standards and methods of administration and recording were defined.

"Preliminary data indicated that no single visual screening device among those studied was more reliable in all respects than any other.

"Study of the problem of near vision versus far vision does not substantiate the hypothesis that a measure of far acuity is an adequate index of acuity for near objects.

"Similarly, the evidence does not indicate that a measure of lateral heterophoria for distance is an adequate index of lateral heterophoria for near vision.

"The distribution of interpupillary distances for 3066 enlisted men examined at the Submarine Base, New London, is presented. It is observed that the average interpupillary distance for this selected population exceeds that for a standard population previously reported in the literature.

"The following reliability coefficients were obtained for the Ortho-Rater, based on a large population of candidates for Submarine training:

(a) Distance acuity...............0.72
(b) Lateral phoria (distance).....0.84
(c) Lateral phoria (near).........0.86

It is reported that there is no indication that binocular presentation of test-targets, as accomplished in this device, renders the measurement of single-eye acuity unreliable. Furthermore, the hypothesis that lateral heterophoria scores derived from this instrument are related to interpupillary distance may be dismissed."

131. Visual Acuity Measurements With Three Commercial Screening Devices.
Sulzman, John H; Cook, Ellsworth, B; and Neil R. Bartlett. Progress Report No. 2, BuMed Project No. x-493 (Av-263-p) Medical Research Department, U. S. SubBase, New London, 7 February 1946, 43 pp., Open

"The procedure for evaluating visual screening devices from the standpoint of validity is outlined, and treated from a methodological and theoretical standpoint.

"Results are presented on comparative efficiencies of three instruments (Keystone Telebinocular, Bausch and Lomb Ortho-Rater, and American Optical Sight Screener) for measuring visual acuity.

"In order to compare the instruments with a reasonable standard, it was necessary to construct indices for near and far acuities that are more reliable than scores with commercial Snellen charts. These improved measures were employed as criteria for assessing the validity of the scores yielded by the three instruments.

"The comparative reliability of each of the devices was determined by computing the consistency of measurement. 128 observers were examined twice and the reliability was calculated by analysing the data on first and second examinations.

"Of the three instruments, the Keystone Telebinocular proved inferior in both validity and reliability to the Ortho-Rater and the Sight Screener. No choice between the other two is indicated, in the opinions of the writers.

"In every instance, the reliability of measures of acuity for distance is greater than the reliability of measures for near.

"Evidence is presented showing that selection of personnel for near-point operations should be based on near acuity measures rather than on far acuity measures.

"The reliability of measurement with screening instruments, (following procedures prescribed by the manufacturers), is inferior to that of letter-chart tests conducted according to the method outlined herein. However, the reliability of any test may be modified by simple changes in test procedure."

132. Abstract of the Scientific Work of Professor G. von Studnitz and His Assistants.

Professor von Studnitz, "an expert in Zoology and related Physiology, specializing in eyes, sight, and color blindness",

has been retained by the U. S. Group Control Council (Germany). The following abstract of his scientific work was prepared by the Office of the Director of Intelligence, Field Information Agency, Technical. American scientists interested in "exploiting" Professor von Studnitz should request it immediately. Address:

FIAT, c/o USFET Main
APO 757, US Army

Abstract: "In the beginning of 1942, the Supreme Command of the German Navy (and a little later also that of the Luftwaffe and Army) asked me, who had worked for 12 years about photo-chemistry of vision, if it would be possible to rise dark adaptation of the human eye: that means to enable a better and quicker recognization in the dark and dim than in normal estate; a problem, which they held of greatest importance for submarines, night-fighters, a.s.o., not only in war-, but also in peace-time.

"I thought it possible by a medicamental influence on the photolabile substances causing vision, and one year later, my collaborators and I had developed a drug, by which the retina reached an estate of sensitivity twenty-five fold above that of the normal eye in the same time as usual dark-adaptation. Because of missing the raw-material for this drug, this could not be further developed or employed in a greater measure.

"Besides these researches we had begun other ones which led, in Autumn of 1943, to another drug with a comparable but much more persisting effect, a further advantage of which is, that it may be got in each quantity from certain plants containing the raw-material. In 1944 they were built and the drug was manufactured in a more expansive manner. Its first introduction into some units of the Navy happened in February and March 1945. Further experiments of our own to simplificate the treatment with this drug and make it more effective were interrupted at the same time.

"In former years I had succeeded to find the 3 photolabile substances which enable day-and colour-vision and to develop a new theory of this kind of vision and the different types of colour-blindnesses. In the course of the above-called researches we furthermore succeeded in getting designs of the chemical constitution of the 3 "colour-substances" and began to prepare respective drugs to influence resp. heal colour blindness. This was possible, in the first few cases we could study until Spring 1945, for persons with weakness in seeing green, whereas development and examination of respective drugs for other types of colour-blindness would afford further researches. These experiments also were assisted by the Supreme Command especially of the Navy and

Luftwaffe, since 7-10% of all male people is colour-abnormal and therefore not fit for professions as sailor, flyer, railway-employees, a.s.o.

"The nearer exploration of the above-called colour substances let us hope to make visible one day rays not yet visible, as those of the ultra-red space of the spectrum. These studies, basing especially on the researches of my cooperator Dr. Loevenich, also claim the greatest interest as well in practical as in theoretical respect.

"The special apparatures necessary for the above researches and its continuation, as well as all important protokols, papers a.s.o. were removed with me from Halle and find in my luggage at Klein-Gerau and Darmstadt."

133. <u>Influence of Carotenoids on Dark Adaptation in Man.</u>
von Studnitz, G; Wigger, H; and H. K. Loevenich

The Office of Military Government for Germany (US) obtained a manuscript prepared September 4, 1944 summarizing the work of German scientists on improvement of dark adaptation by certain carotenoids. A summary was prepared by the Office of the Director of Intelligence, Field Information Agency, Technical:

"Carotenoid containing extracts of the dried flower <u>Tagetes patula flore pleno</u>, consisting mostly of Lutein, were fed in emulsified form in Sesame or olive oil. A sharp response of 8-10 fold in the rods and a 3-4 fold cone response over the normal was noted. After cessation of the feeding of the supplements this effect slowly fell off.

"The flowers were grown on a small plot 240 yards square by Prof. TROLL. The flower portion of the plants was gathered 2-3 times a week, dried overnight at 40-45° C. ground to a meal and stored in a cool place in the dark. Lutein dipalmitic acid ester was prepared from the meal by Prof. BROCKMAN as follows: Three extracts of the meal with hot methanol were followed by extraction with 90% acetone and finally by standing for 12 hours in 100% acetone. In the next step, which consists of refluxing the residue with 100% acetone, the Lutein dipalmitic acid ester goes into solution. The filtrate is allowed to cool to room temperature and the precipitated sterols filtered off. The filtrate is further cooled in the ice chest and the ester precipitates at this point. An orange colored amorphous product of m.p. approximately 62° C results. One per cent of this product can be dissolved in Sesame or olive oils by heating to 40-45° C. The dark red oil solution is emulsified with 50 parts Gum Arabic and 1,500-2,000 parts of distilled water.

"The material is administered by mouth 3, 6, and 9 hours before the measurement of the dark adaptation ability of the subject. Cone adaptation was measured by means of the Nyktometer using the method of Comberg; rod adaptation employed the method of NAGEL and also that of NOWAK-WETTHAUER using the Adaptometer.

"The doses of Lutein ranged from 100 mg. - 600 mg. per subject per day. Since the Lutein preparation contained 1% beta-carotene the effect of pure beta-carotene on cone and rod adaptation was ascertained. The Lutein effect was distinct from that due to the beta-carotene present."

134. <u>Vision in Air Sea Rescue Search</u>
E. S. Lamar
Operations Evaluation Group Study No. 250.
Operations Evaluation Group, Office of the Chief of Naval Operations; January 18, 1946, 14 pp. C.

Operational data concerning detections made in air sea rescue search have been analyzed in the light of a theoretical treatment, based in part upon laboratory data of Craik.

<u>Conclusions:</u>

"The range at which a given target can be seen in daylight is largely determined by its apparent area and contrast, its shape and color being of only minor importance.

"The contrast of a given target is dependent upon the altitude and relative bearing of the sun, and upon atmospheric haze. No effect of cloud cover or sea state was detected for cloud covers ranging from 0.2 to 0.7 inclusive or for sea states ranging from 2 to 4 inclusive. Further trials are needed for sea states in excess of 4.

"Daylight air-sea rescue search is most effective between mid-morning and mid-afternoon, i.e., when the sun's altitude exceeds 30°.

"Parallel sweep search is more effective if the successive legs are up or down sun than if they are across sun. For the up sun sweep, the lookout assignment should include one man in the tail gun position in the aircraft.

"The lookout assignment should provide for uniform coverage of the forward 180° of azimuth, with an additional lookout in the tail gun position to cover the aft 45° during the up sun runs.

"Scanning should be carried out almost entirely along a line a few degrees below the horizon with only short glimpses closer

in. This results from the fact that the "corner of the eye" can be relied upon to sight most of the targets near the aircraft.

"In the present stage of the art, naked eye search is more effective than binocular search from aircraft in daylight.

"The 'Learned signalling mirror' can be seen much farther from an aircraft than the aircraft can be seen from a life raft, provided of course that the sun is not obscured by overcast. Hence, making contact with the aircraft depends upon the abilities of the life raft occupant as regards search and skill in using the mirror. The advantage of training and drill in the use of this excellent piece of equipment cannot be overemphasized.

"For sea states of 6 or less, the average range of pick-up of Dye Marker - Life Jacket Packet, is more affected by time in the water than by sea state. Further trials are needed for sea states in excess of 6. This average range reaches its maximum value about 15 minutes after the packet is in the water. At the end of about an hour, the average range drops to about half its maximum value.

"Since the use of mirrors, dye markers and other means of making contact requires that the occupant of the life raft first detect the search craft, aircraft for air-sea rescue operations should be made as conspicuous as possible. For daylight search this is best accomplished by painting the aircraft black.

"Naval or other personnel in life rafts should scan uniformly over a line a few degrees above the horizon. Training in scanning and in the use of mirrors, dye markers and other means of making contact is of the greatest importance for all prospective subjects of air-sea rescue search.

"The quantitative conclusions concerning the ranges at which various targets can be seen and theprobabilities that they will be seen with any given parallel sweep spacing are given in an appendix."

135. A Study of Pupil Size at Low Levels of Illumination. Irving H. Wagman, Johnson Foundation, Univ. of Pennsylvania. Section 16.1 Report No. 134; OSRD Report No. 6098; October 15, 1945; 14 pp. R

"A study was made of pupil size at low levels of illumination in relation to the design of the exit pupil of night binoculars.

"Pupil size was measured at these low brightness levels by an infrared photographic method on 10 observers.

"An analysis has been made of a British report on an extensive survey of pupil size. It has been shown by this analysis that the most satisfactory expression of pupil size is in terms of area. The distribution of average area of the population is normal.

"The curve relating pupil area and log brightness has been accepted as standard. By calculating the average deviation of only a few measurements made on one observer at one or more brightness levels, from this standard curve, this observer's pupil area at any brightness may be obtained.

"The curve shows a break in the region of 1 ul, suggesting the separation into rod and cone functions. It is, therefore, similar to curves describing other visual functions, such as brightness discrimination, visual acuity, threshold sensitivity to light.

"The distribution of average area of the population makes possible the choice of the proper exit pupil of night binoculars. This choice must, of course, be a compromise with size and weight of the instrument.

"The results obtained on the 10 Brown observers agree quite well with those of the more extensive British survey.

"The total variance of pupil area consists mainly of the variance of the average areas of the population. The individual fluctuations in pupil area from moment to moment and from day to day play a small part in the total variance.

"At a constant brightness, the size of field must be varied considerably to make a significant difference in pupil area.

"The results of an experiment on the effect of accommodation on pupil area indicate that the binoculars must be markedly out of focus before a significant effect on area and thus on range is obtained."

136. <u>Factors Influencing the Magnitude of Range-Errors in Free Space and in Telescopic Vision.</u>
<u>NDRC Report to the Services No. 100.</u> Division 7, Fire Control. July 1945, 7 pp. R.

Fundamental laboratory and field studies (see Abstract 137) have indicated that there are three important cues for normal stereoscopic vision, namely binocular parallax, size-difference and definition-changes (assumed to be effected by wave-front difference). If all these cues are available, as in normal vision, the angular range-error is only 0.03-0.05 seconds of

[redacted]

arc. This precision is some 200 times better than the theoretical expectation computed solely on the basis of the binocular parallax angle available to an observer. Also, thelinear range-error is independent of magnifying power for any given range and the relative range-error is nearly, though not exactly, independent of range.

137. Factors Influencing the Magnitude of Range-Errors in Free-Space and Telescopic Vision.
Holway, Alfred H; Jameson, Dorothea A; Zigler, Michael J; Hurvich, Leo M; Warren, A. Bertrand; and Ellsworth B. Cook.
Division of Research. Graduate School of Business Administration, Harvard University. August 10, 1945. 314 pp. R.

The impressive body of experimental data is presented, upon which the conclusions given in Abstract 136 above are based.

138. A New Fundamental Design of Stereoscopic Rangefinders.
NDRC Report to the Services No. 106. Division 7, Fire Control. December 1945. 3 pp. R.

As a result of the experimental data described above in Abstracts 136 and 137, it was concluded that "no considerable improvement in ranging acuity may be expected from redesign of the present conventional stereoscopic instruments which employ solely binocular parallax as cue to the observer. By such redesign of existing instruments only a small fractional factor of improvement in acuity may be anticipated. On the other hand, a redesign which will make available to the observer size-difference and wave-front difference cues in addition to binocular parallax cues promises to pay huge dividends in the way of reduced range-errors.

"At Harvard University an experimental instrument embodying these features has been designed and a bench model built (see Abstract 139). Apart from its embodying the three distance cues, this instrument is quite unconventional in another respect, namely, that it is equivalent to a single objective instrument in which the image volume is viewed stereoscopically by a binocular microscope as contrasted with the conventional rangefinder in which object space is viewed stereoscopically employing two completely separate and independent optical paths. This single-objective feature should not, however, be confused with the feature of simultaneous and concordant employment of all three distance cues which is an entirely separate and unrelated matter as far as theory of the instrument is concerned.

[redacted]

"The particular instrument here described is applicable in its present design form only to relatively small ranges such as might be used for tanks, landing craft, mortars, etc. This range limitation, however, is associated not with the three-distance cue characteristic but with the single-objective characteristic. It is possible that modifications in which, for example, a mirror is used instead of an objective, might make practicable the design of an instrument for larger ranges that would not be unduly bulky.

"Because of the end of hostilities and the subsequent closing of NDRC activities, it was not possible to develop this instrument beyond the bench model stage. However, Harvard University has produced a usable, handheld item which may be employed for the taking of ranges from 250 to somewhat beyond 1,000 yards and which certainly illustrates the fundamental design principles involved."

139. A New Stereoscopic Range-Finder Based on Three Distance-Cues.
Holway, Alfred H; Jameson, Dorothea A.; and Leo M. Hurvich
Division of Research, Graduate School of Business Administration. Harvard University. December 5, 1945. 17 pp. R.

Details are given of the rangefinder of new design, described in brief in Abstract 138.

140. Measurements of "Visual" Fields with the Perimeter under Conditions of Physiologic Stress.
Blum, Harold F. and M. Bruce Fisher
Naval Medical Research Institute Research Project X-149, Report No. 1, November 26, 1945, 8 pp. Open

"Measurements of visual fields with the perimeter are highly reliable when made by a single operator using a single technique, but differ by a few degrees for different operators.

"With repeated measurements by the cut-in technique the perimetric field size decreases, the decrease being relatively irreversible. This decrease appears to result from a change in the subject's reaction or criterion, and is not based on a general physiologic change.

"The reduction in perimetric field size which has been observed in subjects exposed to prolonged physiologic stress not involving anoxia, are probably no greater than those observed under non-stress conditions. Thus, this type of measurement does not seem valid as an index of physiologic change under such circumstances.

"Acute anoxia produces reversible reduction of the perimetric fields, apparently due to physiologic changes in the visual mechanism."

141. Notes on the Scattering of Light in Optical Fire Control Instruments.
Coleman, Howard S. and Samuel W. Harding
Section 16.1 Report No. 144; OSRD Report No. 6108,
October 19, 1945 19 pp. R.

"The effect of the scattering of background light in optical fire control instruments has been considered. In devising means of studying this problem, three new pieces of equipment have been developed.

"Preliminary investigations involving the use of the above-mentioned apparatus demonstrates the fact that there is scattering of light present in telescopes of the M71, M72, and M76 types when there is a bright surround (outside of the field of view). This scattered light in the instruments reduces the contrast of the image formed in the telescope.

"A study of the resolving power of the eye was made using targets in which the line density was made to vary continuously from the white part to the center of the black part of the lines, in an effort to stimulate targets which might be seen through an instrument, especially where scattering is present. It was found that this type of target in itself did nothing to cause a deterioration of the resolving power of the eye at various pupil sizes, at least with the target well illuminated.

"A preliminary comparison of the performance of the two M71 telescopes, one with coated optics, and one with uncoated optics, indicates that the coating does nothing to reduce the amount of scattering of light in the M71 telescopes, and in fact probably makes the detrimental effects more noticeable."

142. Visual Effectiveness of Low Reflectance Coatings Applied to Transparent Areas of Aircraft.
Chapanis, Alphonse and Stanley Schachter
AAF. ATSC. Engineering Division Memorandum Report.
Serial No. TSEAL 3-695-62. October 31, 1945. 24 pp. Open

Three optical characteristics of low reflectance coatings were considered in terms of their effect upon visual performance: total transmittance, haze, (i.e. scattering) and specular reflectance. Night vision was selected as the most appropriate visual function "because the annoyance value of reflections is greatly increased at night."

It was readily demonstrated that the small increase in total transmittance produced by low reflectance coatings did not affect night vision appreciably. The introduction of haze (amounting to a scattering of 1.5% of incident illumination) by low reflectance coatings, did not impair night vision as tested. The small reduction of specular reflections achieved by coating does not improve night vision as tested.

143. Depth Perception through a P-80 Canopy and through Distorted Glass.
Chapanis, Alphonse and Stanely Schachter
AAF. ATSC. Engineering Division Memorandum Report.
Serial No. TSEAL 3-695-48N. October 22, 1945. 15 pp.
Open.

Depth perception, as measured by the Howard-Dolman apparatus, is impaired in scanning through the forward section of a P-80 canopy. The impairment is greater through the two curved plastic panels than through the bullet-resistant glass.

Large angles of incidence impair depth perception less if the glass is tilted back (or forwards), i.e., around a horizontal axis, rather than sideways, i.e., around a vertical axis. This is consistent with the further finding that the main effect of distortion is on the binocular cues of depth perception.

144. The Interrelationship of Visual Acuity at Different Distances.
W. J. Giese
Journal of Applied Psychology, 30, pp. 91-106 (February, 1946) Open.

A group of 489 subjects were tested for visual acuity at distances varying from 10 to 0.2 meters. The Bausch and Lomb multiple-choice checkerboard test was used, scaled appropriately for the various distances investigated. The checker pattern was always mounted in the center of an 8 x 8 inch card. Illumination of the test card was standardized at 8 foot candles, whereas the surrounding room was illuminated to 1 foot candle.

The data of 89 subjects were used to determine the test - retest reliability of the checkerboard test at the various distances. Reliability coefficients were obtained which ranged from 0.72 to 0.93.

The data of 400 subjects were used to determine the intercorrelations of acuity scores at various distances. Scores on tests at different distances were correlated positively but with low coefficients (an average of 0.40). It was emphasized

that selection of personnel for tasks requiring visual performance at one distance could not be accomplished satisfactorily by testing visual acuity at another distance. It was demonstrated that the greater the differences in distance, the smaller were the correlation coefficients.

The mean visual acuity for the group of 400 subjects was shown to vary systematically with distance, as follows:

Distance (meters)	Mean Visual Acuity
0.20	0.95
0.25	1.05
0.33	1.28
0.40	1.37
0.50	1.39
1.0	1.63
5.0	1.61
10.0	1.35

It is evident that visual acuity increases systematically as a direct function of distance between 0.20 and 1.0 meters. An apparent reversal in the trend is demonstrated between 1.0 and 10.0 meters.

Discussion: The explanation of the apparent reversal in the relation between distance and acuity is not clear. The assumption that there are only random differences in acuity for distances between 0.40 and 10.0 meters is hardly justified by the high precision of the experimental results.

Apparently, the only criticism of the research data is that the angular size of the field of high brightness upon which the test object appeared was not maintained constant as distance was varied. Actually, the physical size of the field was maintained at 8 x 8 inches. It is not apparent how this fact can be used to explain the trends of Giese's data.

145. The Dioptometer and Its Use in the Inspection of Optical Instruments.
Howard S. Coleman
Section 16.1 Report No. 141. OSRD Report No. 6105.
October 19, 1945. 14 pp. R

An instrument is described which evaluates the curvature of the wave front of light emerging from the exit pupil of optical instruments. Specific procedures are described for inspecting optical instruments for the following:

Diopter setting of the reticle
Parallax
Accuracy of diopter scale of the eyepiece
Astigmatism
Curvature of the ocular and object fields
Spherical power
Spherical aberration
Chromatic aberration
Resolution

146. <u>Photoelectric and Photographic Procedures for the Evaluation of Optical Instrument Design.</u>
Coleman, Howard S. and David G. Clark
Section 16.1 Report No. 143. OSRD Report No. 6107.
October 16, 1945. 12 pp. R.

Instruments and procedures are discussed for evaluating the extent to which the rays emerging from the eyepiece of a telescopic system depart from parallelism. The most pertinent index was taken to be the energy distribution of a line source.

147. <u>The NDRC Optical Inspection Project at the Pennsylvania State College for the Period of October 1943 to November 1945.</u>
Coleman, Howard S. and Madeline F. Coleman. R.

Under Project OD-138, the Frankford Arsenal requested in August, 1943, that NDRC make a survey of present methods of optical inspection, both in Government shops and in contractors' shops, prepare a report describing and assessing these methods, recommend improved methods, and develop special equipment for use with new methods. The studies and developments on this project have been conducted at the Pennsylvania State College, under Contract OEMsr-1197.

An extensive survey has been made of present methods for inspecting individual elements, subassemblies, and complete instruments. This survey is described in OSRD Report No. 6103, and is the basis for the work that has been done on new methods. Up to the present time, optical inspection has depended to a large extent on the subjective reactions of an inspector. It is desirable that impersonal methods be substituted wherever possible.

One of the most important developments under this project relates to the K.D.C. (Kinetic Definition Chart) Apparatus which gives an almost impersonal measure of the angular resolution of a telescope system. Further work will be necessary in order to establish the full significance of the various

optical and physiological factors involved in this test, but it does undoubtedly provide an accurate means for grading instruments on the basis of resolution. This development is described in OSRD Report No. 6104. The K.D.C. instrument was used extensively to control production of tank telescopes during the last year of the war.

An improved design for a Twyman-Green-Michelson-Interferometer has been developed and two models have been built. Studies have been made to determine the feasibility of inspecting subassemblies and individual elements by observing interferometer fringes (OSRD Report No. 6106). The method appears promising.

In order to establish the physical performance of telescope systems on a strictly impersonal basis, measures have been made of the light distribution, in image space, of rays originating in a line source. These measures have been made by using a modification of the photographic wedge method developed at Eastman Kodak and also by using a traveling slit and recording photoelectric amplifier. This work is described in OSRD Report No. 6107. Either method gives data which are of fundamental importance not only in evaluating various methods of inspection, but also in establishing the characteristics of new designs. It is recommended that measures of light distribution in the images of line sources be made for a number of representative fire control instruments, on and off axis, and at various focal settings, to provide a basis for comparing methods of inspection.

The usefulness of the dioptometer in inspecting telescope systems has been investigated and is discussed in OSRD Report No. 6105. (See Abstract 145)

Methods for measuring the amount of scattered light in fire control instruments have been studied. Some measures of the loss of contrast produced by various systems have been made. This work is described in OSRD Report No. 6108. The report indicates that one tank telescope with coated optics gave lower resolution (at high levels of illumination), than a similar telescope, with uncoated optics. This result, which is most unexpected, is based on limited evidence and should be fully investigated.

The following is a complete list of all OSRD reports which have been published by the Pennsylvania State College under Contract OEMsr-1197:

CON[redacted]TIAL

OSRD NO.	Title
6005	The NDRC Optical Inspection Project at the Pennsylvania State College for the Period of October 1943 to November 1945
6103	Report on Optical Inspection
6104	The Description of the Kinetic Definition Chart (K.D.C.) Apparatus and its Uses
6105	The Dioptometer and its Use in the Inspection of Optical Instruments
6106	The Penn State I-1 Michelson-Twyman Interferometer and its Use in Determining Conformance with Design and In Quality Control of Lenses, Prisms, and Telescopic Systems
6107	Photoelectric and Photographic Procedures for the Evaluation of Optical Instrument Design
6108	Notes on the Scattering of Light in Optical Fire Control Instruments

148. Minutes of Operations Research Group Conference, December 19, 1945
Operations' Evaluation Group, CNO, March 20, 1946. 11 pp. C.

A report is given of a conference at which Dr. E. S. Lamar discussed "visual capabilities in naval operations". The principal physical and physiological factors controlling the functioning of the human eye in naval operations were discussed. Attention was given to problems of camouflage concealment and the converse problems of visual detection. Mathematical techniques were described by which the probability of visual detection can be computed as a function of the number, speed, and orientation of observation vessels. Predictions, based on theory and a few laboratory studies by Craik, were shown to be in general agreement with operational data.

149. Studies in Aided Tracking.
Report to the Services No. 102, Division 7, NDRC. October 1945, 4 pp. R.

[redacted]TIAL

The program set up by Division 7 to investigate the fundamental aspects of tracking is described. A complete list of reports of the contractor, the Foxboro Company, is appended. The conclusions stated in the most recent Foxboro report (see Abstract 150) are stated and discussed.

150. Studies in Aided Tracking.
Memorandum No. 25 to Division 7. The Foxboro Company. August 31, 1945, 43 pp. R.

"This memorandum covers laboratory studies of the characteristics of conventional constant-ratio aided tracking with handwheel or handlebar control. Special laboratory equipment was constructed to provide the equivalent of first-class aided tracking apparatus operated under favorable conditions of visibility, stability and comfort. Synthetic tracking problems were provided to avoid the limitations of transient service conditions.

"These studies indicated that an aiding time constant of about one-third second was optimum for handwheel or handlebar tracking under a wide range of conditions, excluding slewing for which the larger value of about one second was optimum. Tracking error was approximately doubled by removal of the direct component, viz., conversion of the apparatus to velocity tracking and zero aiding time constant; but changes in aiding time constant up to the order of 3 to 1 had comparatively little effect. Considerable variation in gear ratio also could be tolerated, the optimum ratio providing a velocity sensitivity of about one mil per degree. The apparent sensitivity, which relates what the operator actually sees to what he does, is generally a much more significant factor than the mechanical sensitivity of the apparatus; though an exception is provided by the case of high sensitivity handlebar turret tracking where high accelerations are frequently encountered.

"Magnification of the apparent target motion by a telescope was found generally to be beneficial, though the improvement appeared to depend on the balance of visual and manipulative difficulty in the tracking problem. In one handwheel test, a four-fold increase in magnification increased the accuracy about 250 per cent, while in a handlebar test, a three-fold increase in magnification increased the accuracy about 15 per cent.

"The importance of the effect of other conditions of performance may be contrasted with the observed error ratio of about 2 between velocity and aided tracking. For instance, the poorest of eight highly practiced operators made an error 8

times that of the best operator. Such a result indicates the need of operator selection and training to obtain highest accuracy. Another important type of condition is apparatus quality, because such an imperfection as backlash can raise the tracking error substantially. For instance, 45 degrees backlash at the handwheel raised the error over 50 per cent when the aiding time constant was one-third second.

"It is interesting to note that the characteristics of the M2 tracker, used in connection with the well-known M9 and M10 electronic directors, are within the optimum range revealed by this study. The aiding time constant of the M2 tracker is 0.4 second, while the apparent direct sensitivity is 0.22 mil per degree, for a telescope magnification of 8.

"For handlebar tracking, a velocity sensitivity substantially above the optimum normally must be used to obtain the required sight velocity to track close-range targets with the permissible movement of the handlebar control. Variable velocity sensitivity is commonly used to provide more nearly optimum conditions for low velocity long range targets. Such variable sensitivity appears to be disturbing to operators, and since tracking error is not too greatly increased by velocity sensitivities several times the optimum, the belief is that for best tracking results the sensitivity variation in the tracking range should be kept moderate (of theorder of two to one) and that a separate slewing range of very high sensitivity can be provided. This conclusion is tentative and it appears that handlebar tracking problems should be individually considered in their entirety, due to the complex compromises required.

"The appendices of this memorandum include tables of experimental results, descriptions of tracking apparatus, definitions of technical terms, and a variety of discussions of theoretical and practical problems."

151. <u>The Sensitivity of the Human Eye to Infrared Radiation.</u>
Wald, George; Griffin, Donald R; and Ruth Hubbard, Harvard University.
Report submitted to the Engineer Board, Fort Belvoir, Project XRS441. July 14, 1945, 80 pp. Open.

"The purpose of the investigation was to obtain, for the engineering of military devices, basic data regarding human vision in thenear infrared. The choice of topics investigated has been governed entirely by military needs, but little or no attempt is made to accomplish the direct application of the information to the design of testing of military equipment. This step must be carried out by those directly engaged in the development of such devices, each device for itself.

"Besides bringing together background knowledge and literature references, the authors present results as follows:

"Experimental tests, by the threshold method, of Goodeve's infrared luminosity function, applied here to foveal vision. Their results confirm the applicability of Goodeve's function to a degree which was hardly to be anticipated from the conditions and small number of subjects which he used.

"Determination of the infrared luminosity function for the periphery of the eye, both for itself and in relation to the foveal function.

"By comparison between the visual transmissions of infrared filters as determined first by the threshold method and then by brightness matching, it is established that concordant results as to luminosity and visual transmission are yielded by the two methods. (The brightness matching was done by Dr. Richard Tousey, at the Naval Research Laboratory.) This agreement extends the similar agreement which has generally been reported in the ordinary visible spectrum.

"Distribution of infrared sensitivity in the population.

"Variation of source visibility with angular size, for both the fovea and the periphery, and the application of associated ideas to the reduced-scale determination of visual ranges of infrared sources."